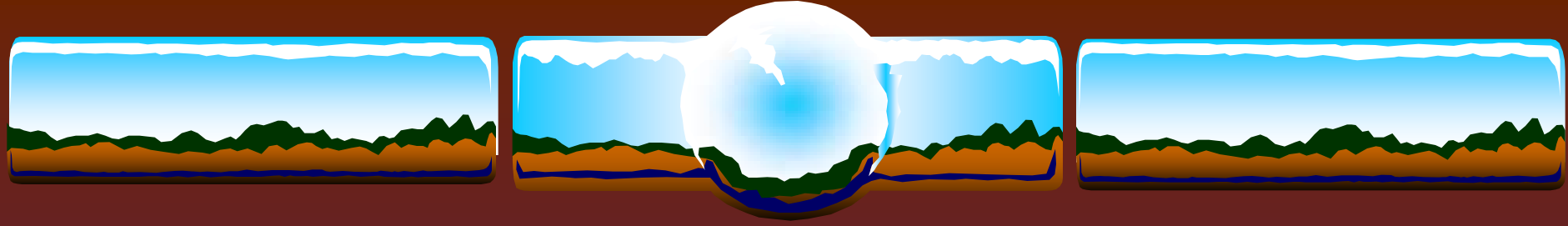
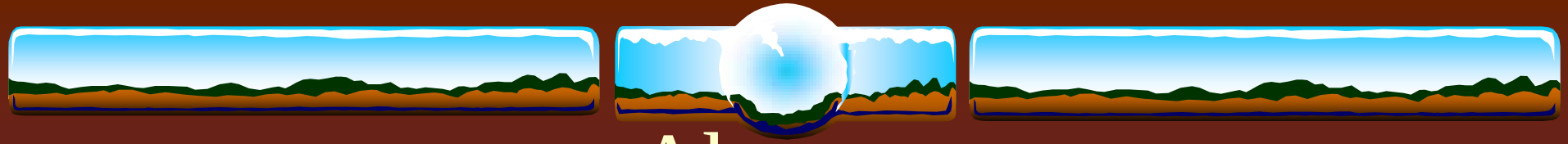


Were the Dark Ages Triggered by Volcano-Related Climate Change?

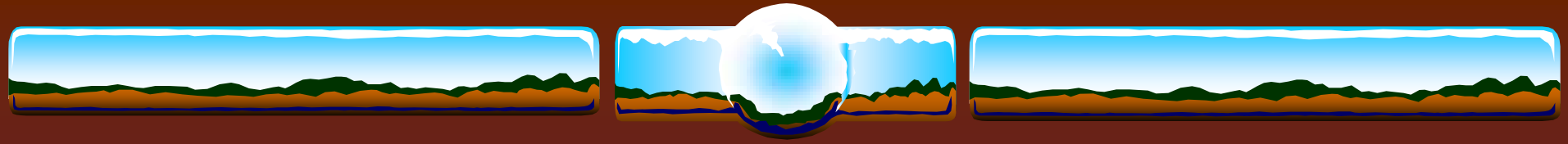
Ken Wohletz

Los Alamos National Laboratory



Abstract

Modern history has its origins in the tumultuous 6th and 7th centuries. During this period agricultural failures and the emergence of the plague contributed to: (1) the demise of ancient super cities, old Persia, Indonesian civilizations, the Nasca culture of South America, and southern Arabian civilizations; (2) the schism of the Roman Empire with the conception of many nation states and the re-birth of a united China; and (3) the origin and spread of Islam while Arian Christianity disappeared. In his book, *Catastrophe An Investigation into the Origins of the Modern World*, author David Keys explores history and archaeology to link all of these human upheavals to climate destabilization brought on by a natural catastrophe, with strong evidence from tree-ring and ice-core data that it occurred in 535 AD. With no supporting evidence for an impact-related event, I worked with Keys to narrow down the possibilities for a volcanic eruption that could affect both hemispheres and bring about several decades of disrupted climate patterns, most notably colder and drier weather in Europe and Asia, where descriptions of months with diminished sun light, persistent cold, and anomalous summer snow falls are recorded in 6th-century written accounts. Writings from China and Indonesia describe rare atmospheric phenomena that possibly point to a volcano in the Indonesian arc. Although radiocarbon dating of eruptions in that part of the world are spotty, there is strong bathymetric and volcanic evidence that Krakatau might have experienced a huge caldera eruption. Accordingly, I encouraged a scientific expedition to be led by Haraldur Sigurdsson to the area. The expedition found a thick pyroclastic deposit, bracketed by appropriate radiometric dates, that suggests such a caldera collapse of a “Proto-Krakatau” did occur perhaps in the 6th century. Bathymetry indicates a caldera some 40 to 60 km in diameter that, with collapse below sea level, could have formed the Sunda Straits, separating Java from Sumatra, as suggested by ancient Javanese historical writings. Such a caldera collapse likely involved eruption of several hundred cubic kilometers of pyroclastic debris, several times larger than the 1815 eruption of Tambora. This hypothetical eruption likely involved magma-seawater interaction, as past eruptions of Krakatau document, but on a tremendous scale. Computer simulations of the eruption indicate that the interaction could have produced a plume from 25 to >50 km high, carrying from 50 to 100 km^3 of vaporized seawater into the atmosphere. Although most of the vapor condenses and falls out from low altitudes, still large quantities are lofted into the stratosphere, forming ice clouds with super fine (<10 μm) hydrovolcanic ash. Discussions with global climate modelers at Los Alamos National Laboratory led me to preliminary calculations that such a plume of ash and ice crystals could form a significant cloud layer over much of the northern and southern hemispheres. Orders of magnitude larger than previously studied volcanic plumes, its dissipation and impact upon global albedo, the tropopause height, and stratospheric ozone are unknown but certainly within possibilities for climate destabilization lasting years or perhaps several decades. If this volcanic hypothesis is correct, the global, domino-like affects upon epidemics, agriculture, politics, economics, and religion are far-reaching, elevating the potential role of volcanism as a major climate control, and demonstrating the intimate link between human affairs and nature.

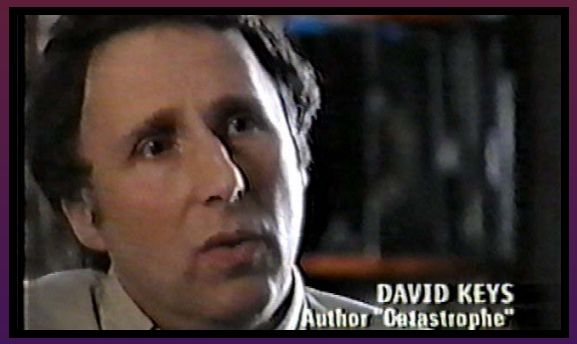


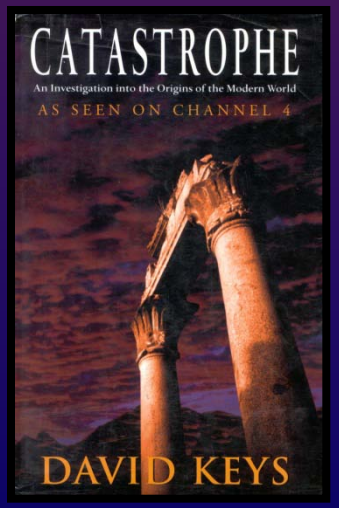
Contents

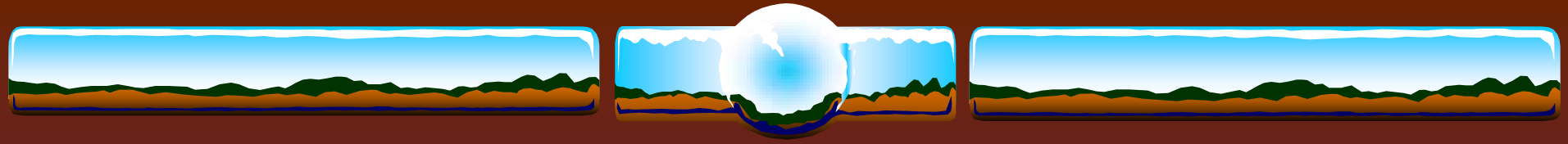
- Introduction
- 6th Century Catastrophe
- Finding the Culprit
- A Proto-Krakatau Model
- Atmospheric Wonderings
- Conclusions

Introduction

- Tree-ring data and historical evidence show clear indications of world-wide climatic chaos in a period following 535 AD
- David Keys, author, verified and documented the history of world-wide political and religious changes that brought on the Dark Ages in his book, *Catastrophe* (Century, London, 1999)

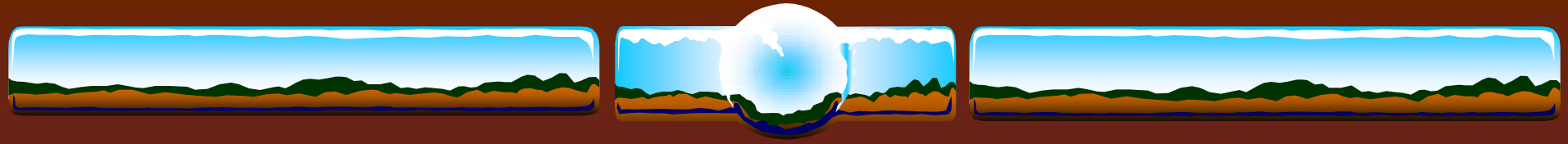






Introduction (cont.)

- Keys contends that a natural phenomenon, namely a volcanic eruption, caused world-wide climatic destabilization that started the complex chain of events bringing about the Dark Ages
- My work focused on finding evidence of such an eruption and determining likely eruptive parameters that could be modeled in order to see in such a climate perturbation might have resulted



6th Century Catastrophe

- Climatic chaos
  - Darkening of the sun for 18 months
  - Marked reduction in temperature
  - Widespread severe droughts
  - Intermittent severe floods
- Agricultural failure
- Increased disease
- Political/religious destabilization

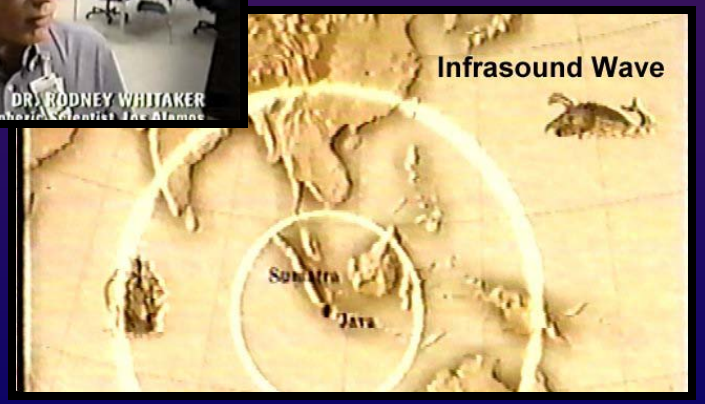
Nan Shi (The History of the Southern Dynasties): December 536

Yellow dust rained down like snow. Then there came celestial ash so thick in places it could be scooped up in handfuls. In July it snowed, and in August there was a fall of frost, which ruined the crops. So great is death by famine that by Imperial decree there is an amnesty on all rents and taxes.

Volcanic hypothesis was discounted in the 1990s because a big sulfuric acid spike was not recognized then in ice cores

Keys found records of thunderous boom from southwest, anomalously reported in the Nan Shi for 535 AD

Rod Whitaker, Infra-sound expert, LANL

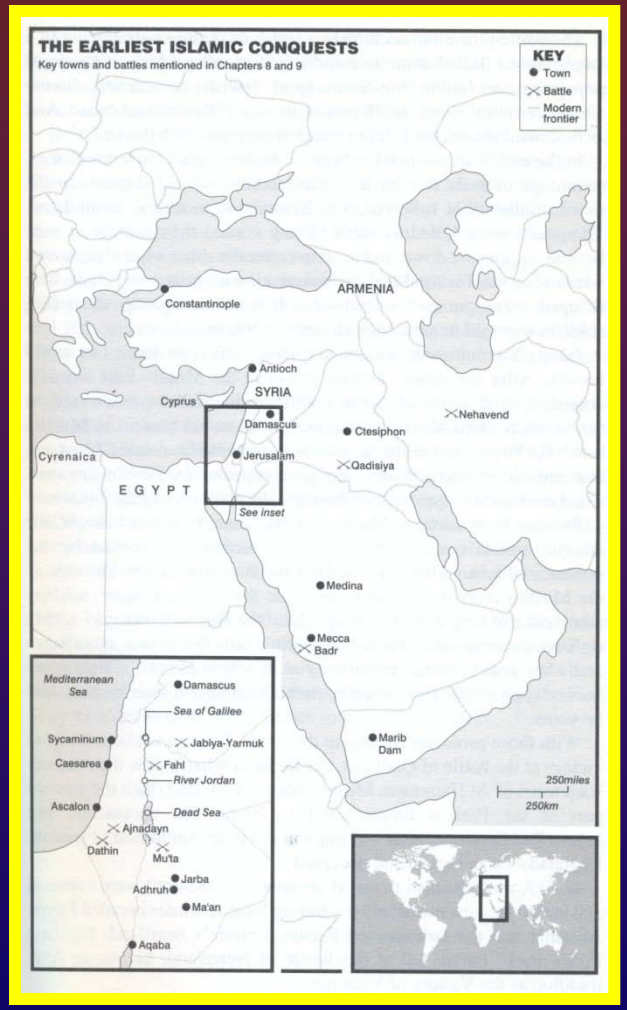


Global Catastrophe

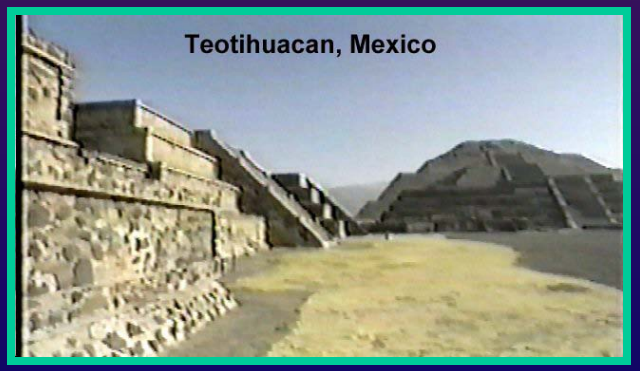
- **John of Ephesus:** *In the sky there was the most dread portent of the hunger and pestilence to come. The sun gave forth its light without brightness like the moon during the whole of this year. God's wrath turned into a wine-press, as it were, and pitilessly trampled and squeezed the inhabitants of the cities like fines grapes,..*

- The Avars, displaced from Mongolia by drought, arrive in eastern Europe in 557–558, and within 20 years they had conquered a significant portion of the land and humbled the Roman Empire

Global Catastrophe (cont)

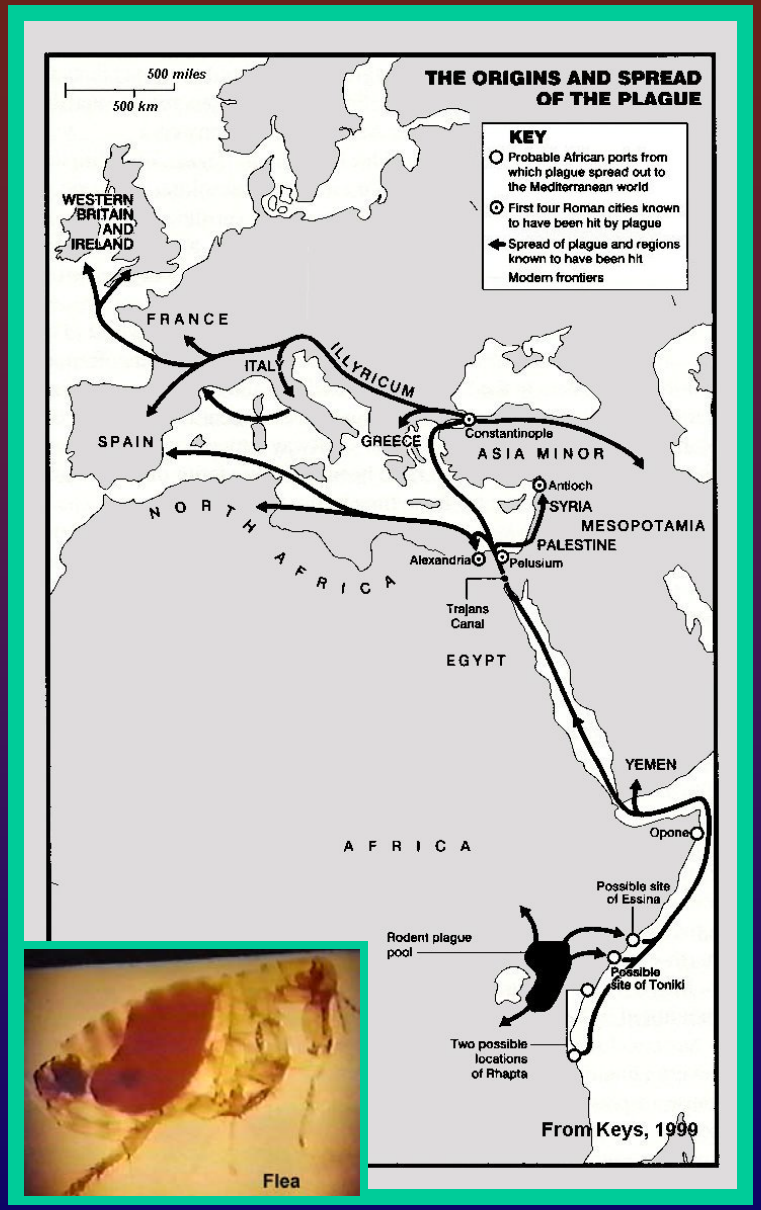


- Two climate-triggered disasters in powerful Yemen, bubonic plague, and destruction of the agricultural economy caused by the collapse of the Marib Dam, led to the growth of Islam and its spread with the weakening of the Roman Empire
- Koguryo, the northern kingdom of Korea, suffered from large weather changes, including flood, earthquake and diseases in year 535
- Teotihuacan civilization in Mexico disappears
- Records from every continent…

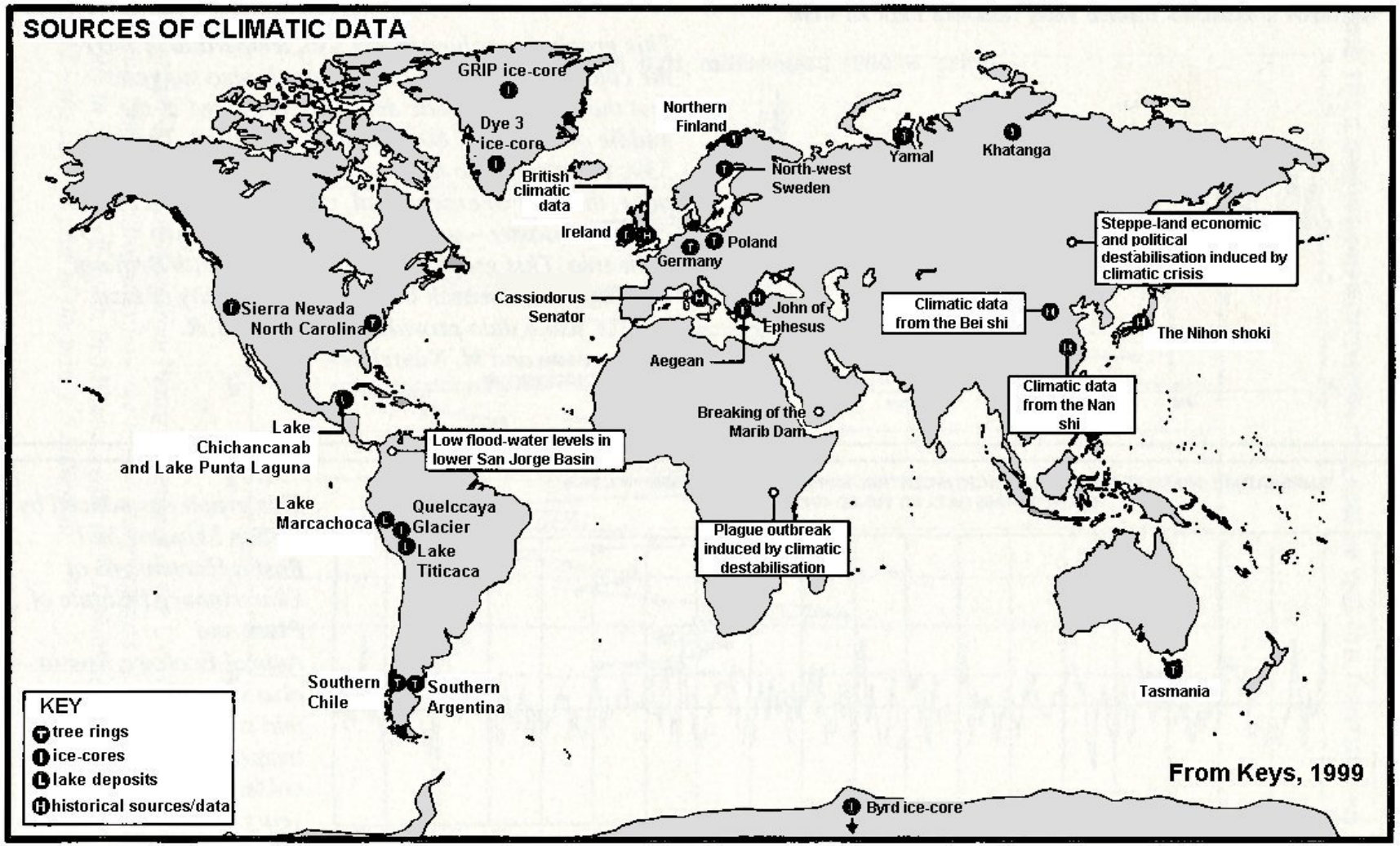


The Plague

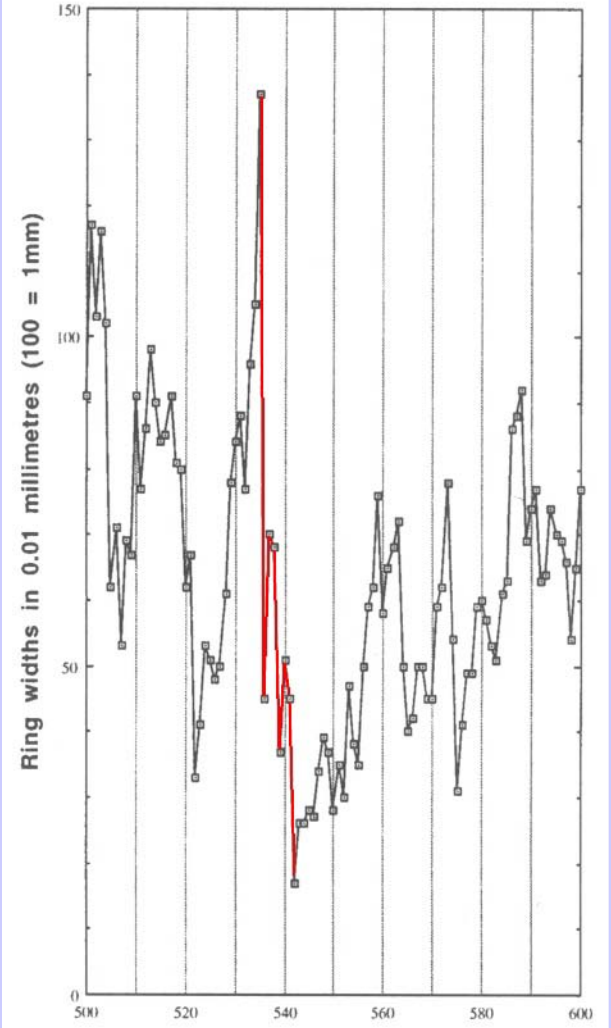
- In 6th century eastern Africa, droughts followed by floods allow rodent population to grow unchecked by predators that had died off
- Rodent swarms invade ships involved in ivory trade bound for Alexandria and Constantinople
- Change in temperature triggers plague bacillus into high gear
- Bacilli block the flea's gut making them voracious
- Fleas bite any warm body multiple times and spread plague through northern Europe,
- Starting *c.* 540, begins a cycle that lasts throughout Dark Ages
- And in 664, abbot Chad unrightfully becomes bishop of York, later to humbly relinquish for sake of peace, leading to his sanctification (St. Chad) after his death from plague…



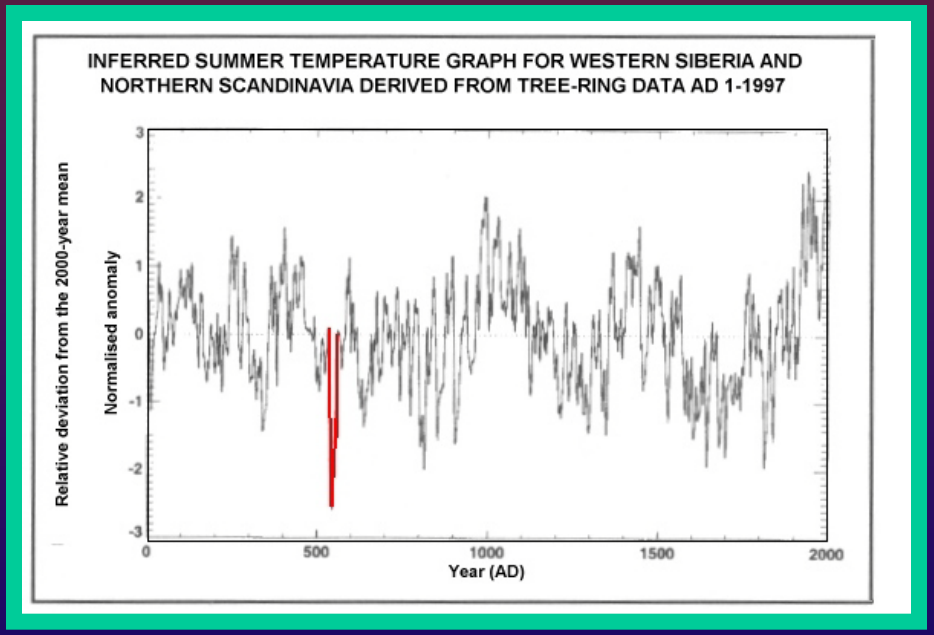
Sources of Climatic Data



Tree-Ring Data

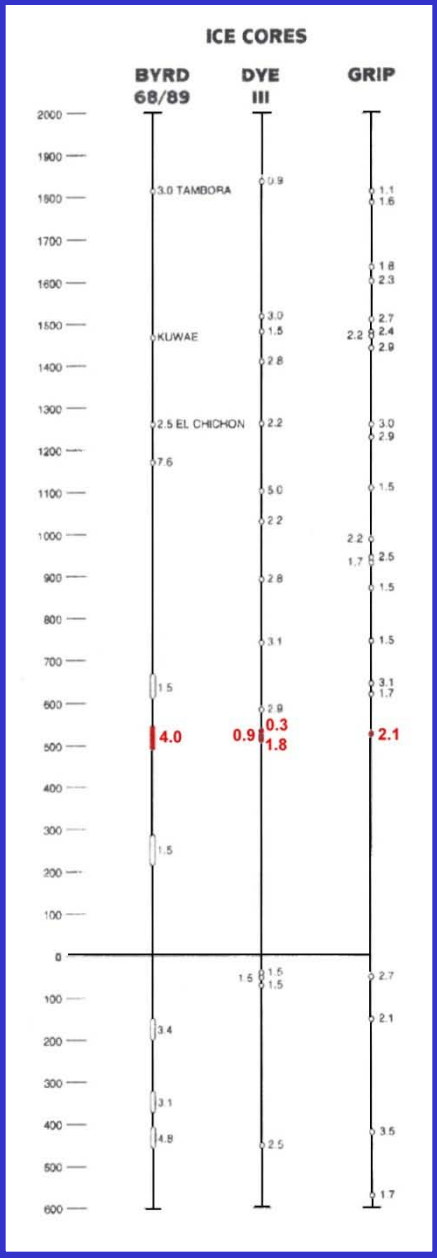


535 AD tree-ring event known for over 10 years in Britain is now recognized world-wide



From: Pentti Zetterberg, Univ. Joensuu, Finnland

From: Keith Briffa, CRU, Univ. East Anglia, corroborated by European data compiled by Mike Baillie, Queen's Univ., Belfast



The Ice Archive

From:

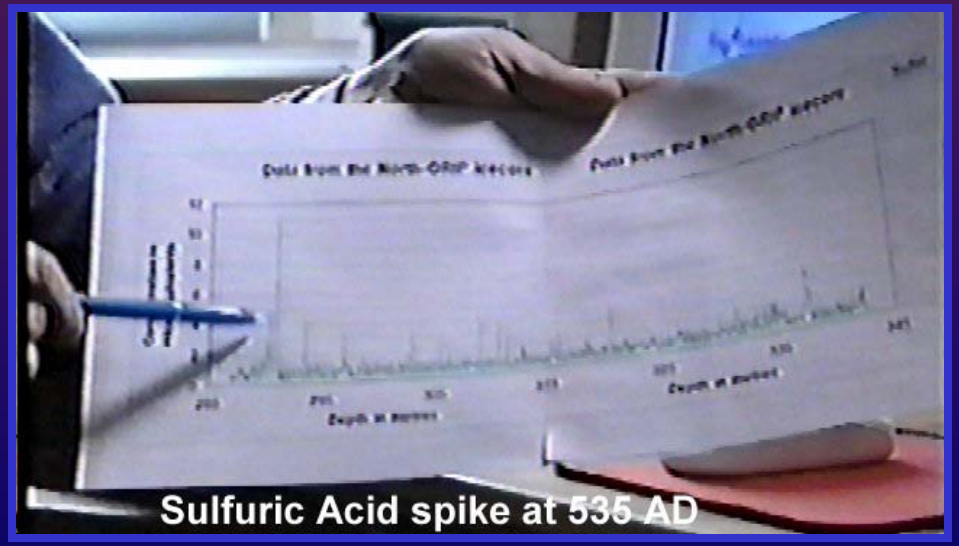
Hammer et al. (*Climatic Change*, 1997)

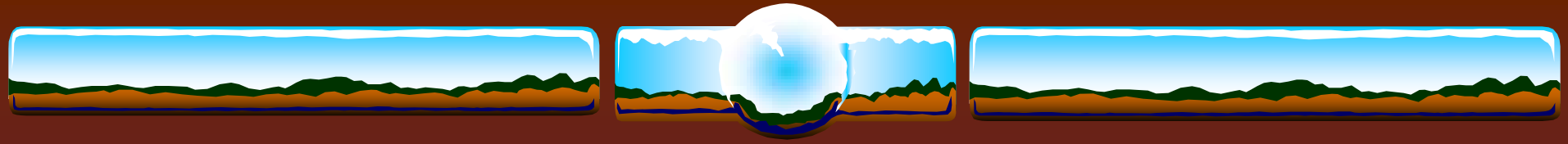
Clausen et al. (*JGR*, 1997)

Zetterberg (Univ. of Finland)

Briffa (Univ. of E. Anglica)

Greenland (GRIP) re-examined and Antarctic (Byrd) core studied to find largest sulfuric acid spike in last 2000 years





Finding the Culprit

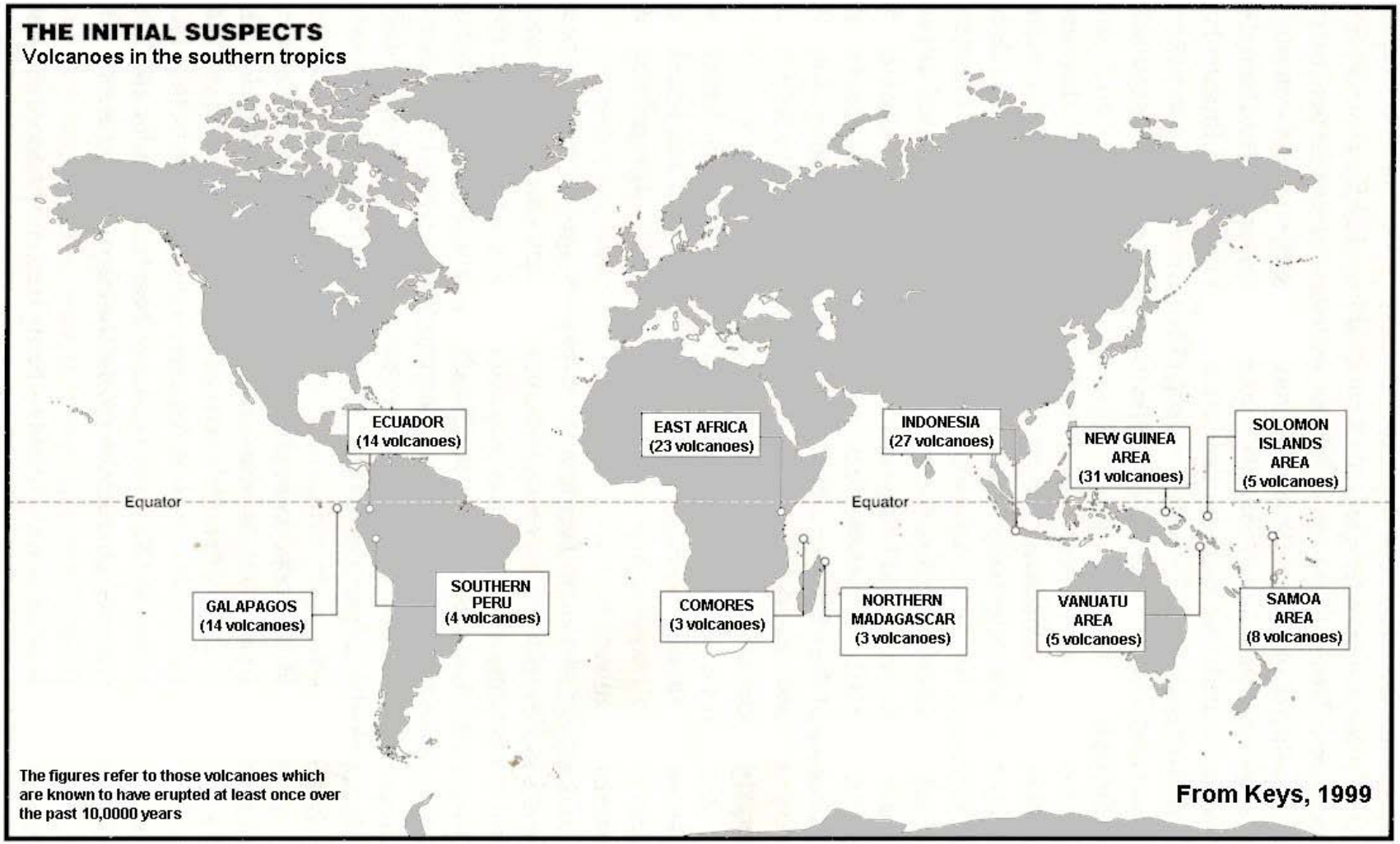
- Two causal options considered
  - Asteroid/comet impact
  - Very large volcanic eruption
- Discounted asteroid/comet option after consultation with leading researchers
  - No known crater of appropriate size for this period of time*
  - Impact in the ocean would have produced “the largest tsunami ever experience by humanity. There is no evidence along coast lines of such an event*
  - An atmospheric explosion would not have created sufficient dust to explain climate changes unless it cause large-scale surface devastation
  - Impact of sufficient size might be a rarer event than large volcanic eruptions

* Madagascar “chevron” deposits of a mega-tsunami point to a newly discovered 18-km-diameter impact crater in the Indian Ocean

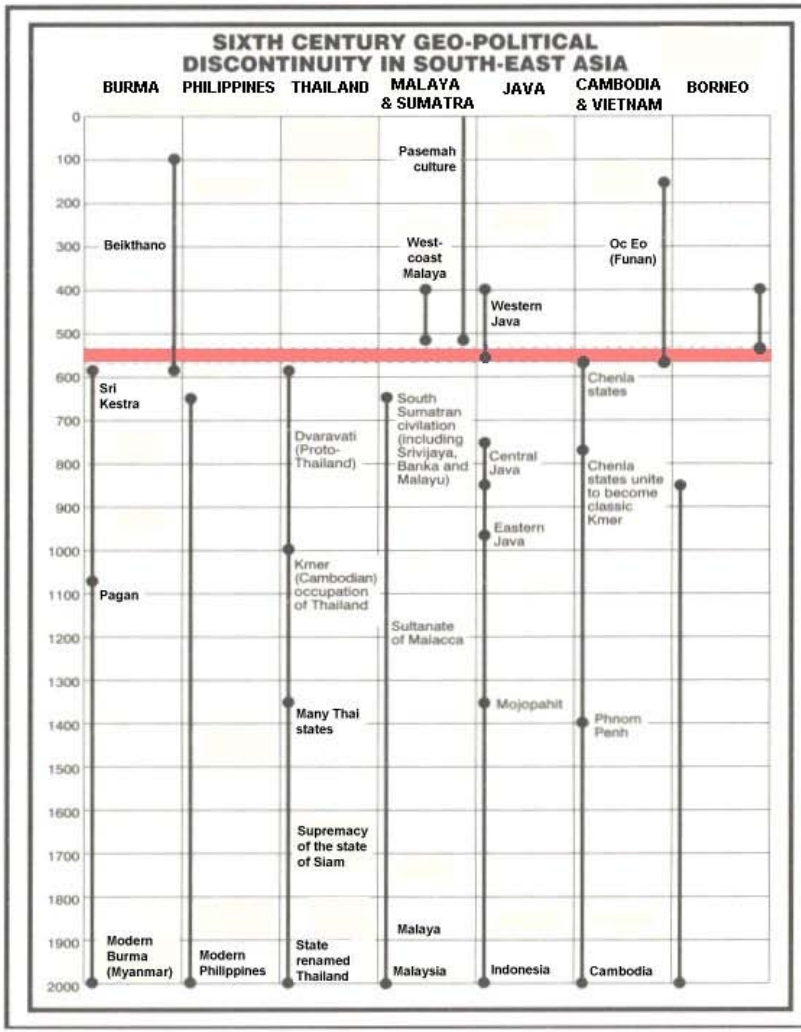
Finding the Culprit (Cont.)

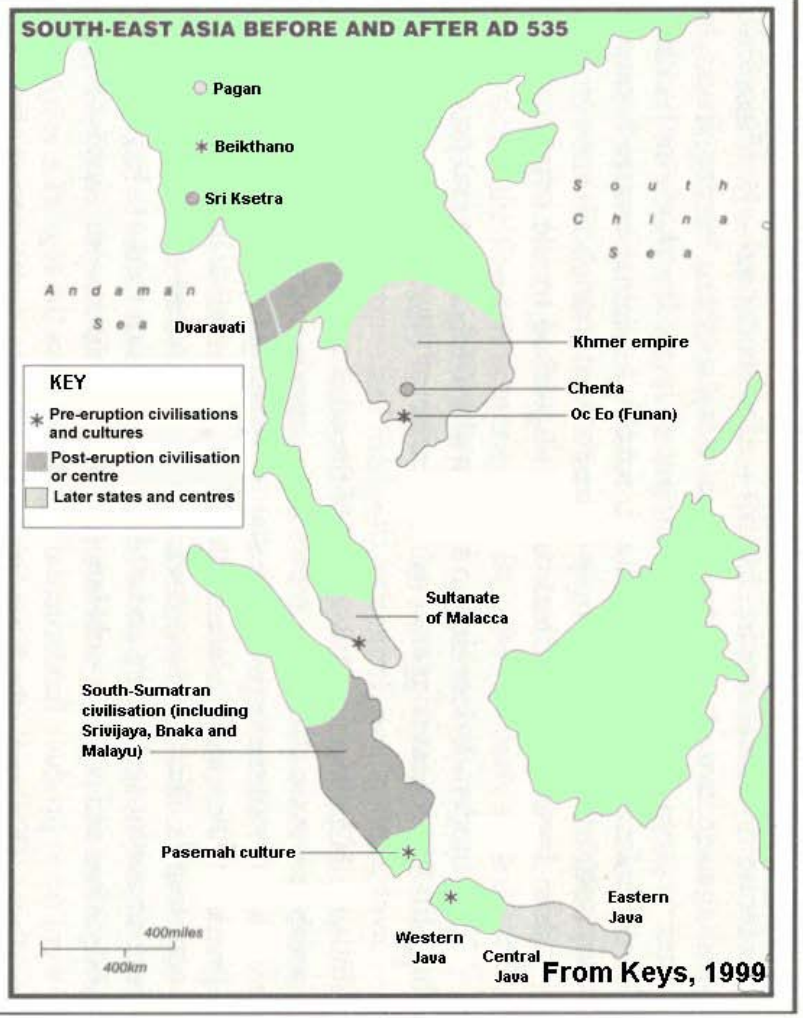
- Volcanic eruption option
  - Greenland and Antarctic ice-cores show a high volcanic acid content in several years around 535 AD
  - Only recent comparable event is the 1815 eruption of Tambora, (*The Year Without a Summer World Climate in 1816*, CR Herrington)
  - A tropical eruption could explain why both hemispheres were affected
  - Chinese records of anomalous “thunder” in the mid 6th century
  - Archaeologically detectable or historically recorded high-cultural activity in Indonesia appears to cease in the mid 6th century and does not re-emerge until the mid to late 7th century
  - Javanese *Book of Ancient Kings* refers to massive eruption of Krakatau in the middle of the first millennium AD (338th year of the Shaka Calendar likely miss-aligned to the western calendar date of AD 416)

Equatorial Volcanoes



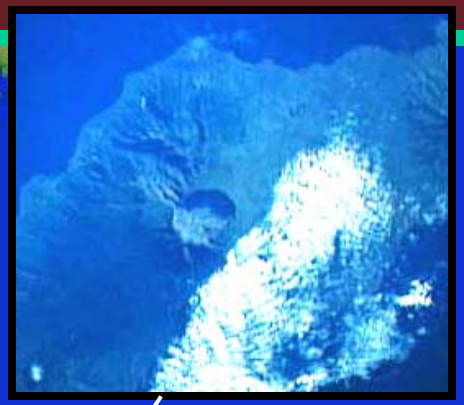
Indonesian 6th Century Geo-Political Discontinuity





Focus on Indonesia

Focus on Indonesia



Pinatubo
Taal
Mayon
Galunggung
Krakatau
Tengger
Tambora
Merapi
Kelut
Batur
Rabaul

Pustaka Raja Purwa (The Book of Ancient Kings, Java)

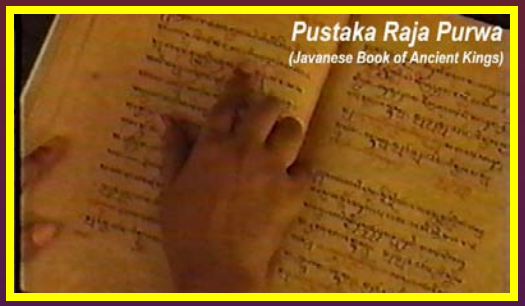
From the earliest surviving manuscript of the chronicles (1869), written on palm leaves:

There was a furious shaking of the earth, total darkness, thunder and lightning.

Then came forth a furious gale together with torrential rain and a deadly storm darkened the world.

A great flood then came from Mount Batuwara and flowed eastwards to Mount Kamula…

When the waters subsided it could be seen that the island of Java had been split in two, thus creating the island of Sumatra.



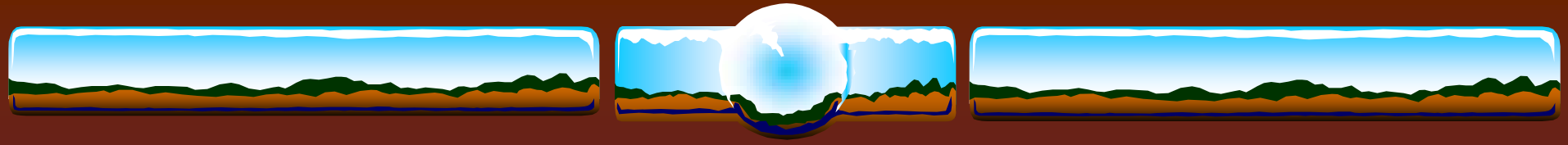
And in a later edition (possibly contaminated by post 1883 editing):

… a great glaring fire which reached the sky came out of the mountain.

But not only did this heavy rain not extinguish the eruption of fire, but it made it worse. The noise was fearful. At last the mountain burst into two pieces with a tremendous roar and sank into the deepest of the earth.

The inhabitants of the northern part of the Sunda country to the Mountain Rajabasa were drowned and swept away with all their property.

After the water subsided the mountain and the surrounding land became sea and the island divided into two parts. This was the origin of the separation of Sumatra and Java.

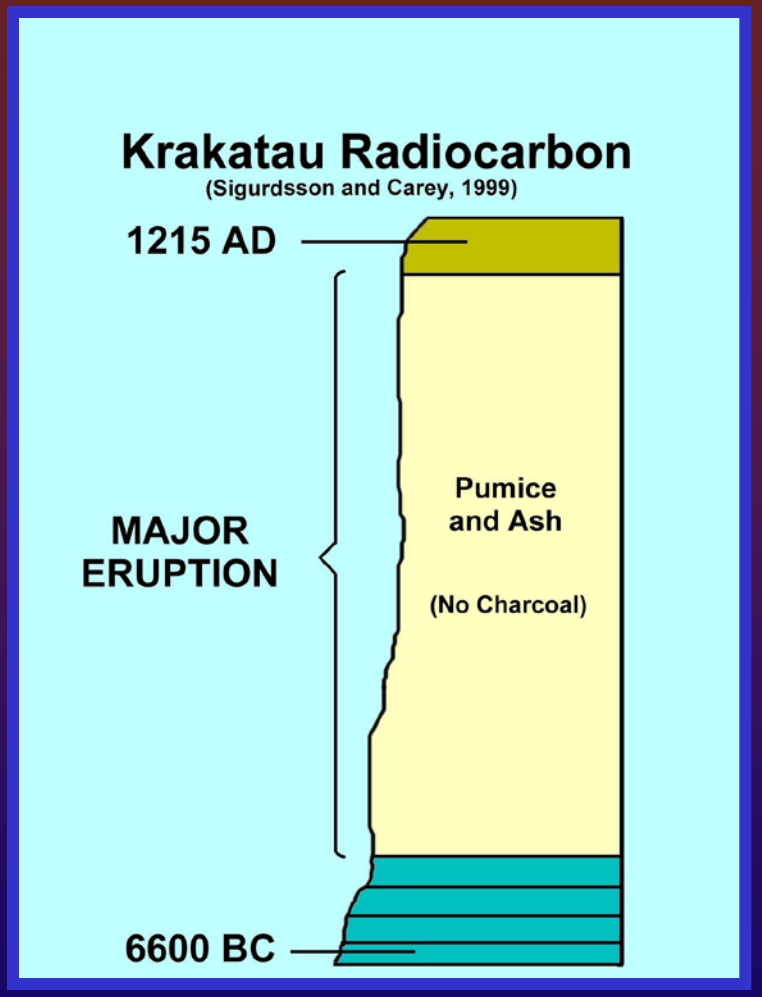


Finding the Culprit (Cont.)

- Why Krakatau?
  - Several Indonesian volcanoes studied (*e.g.*, Rabaul caldera—new radiocarbon dates set its caldera event several centuries later than the old circa 540 AD date) but did not yield dates consistent with the 6th century
  - Krakatau known for repeated activity over the last few millennia
  - Bathymetric evidence of a large (pre-1883) caldera in the Sunda Straits
  - Haraldur Sigurdsson recently documented a thick pumice-and-ash deposit near Krakatau, bracketed in age by radiocarbon dates spanning several thousand years to approximately AD 1000

A *Proto-Krakatau* Eruption

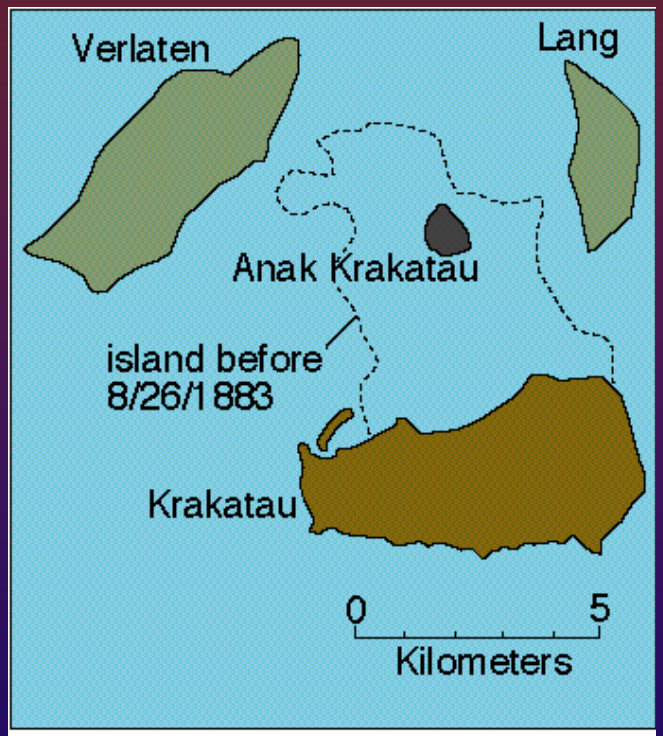
A big eruption occurred, likely in the time frame of the first millennia



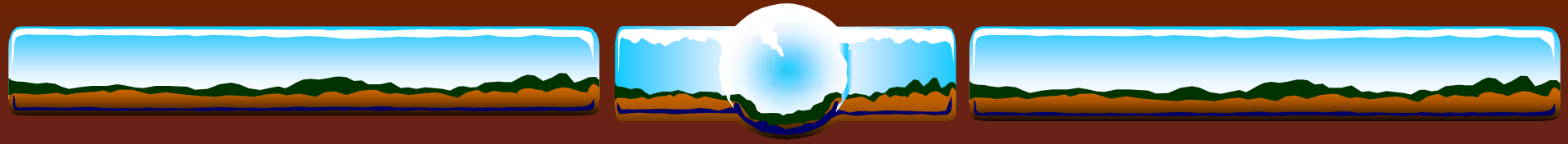
What Krakatau did in 1883

Phreatomagmatic eruption ?

Caldera collapse

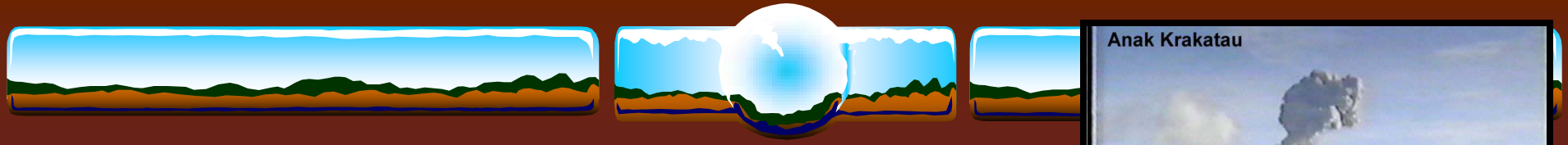


From Simkin and Fiske, 1983



What Krakatau did in 1883

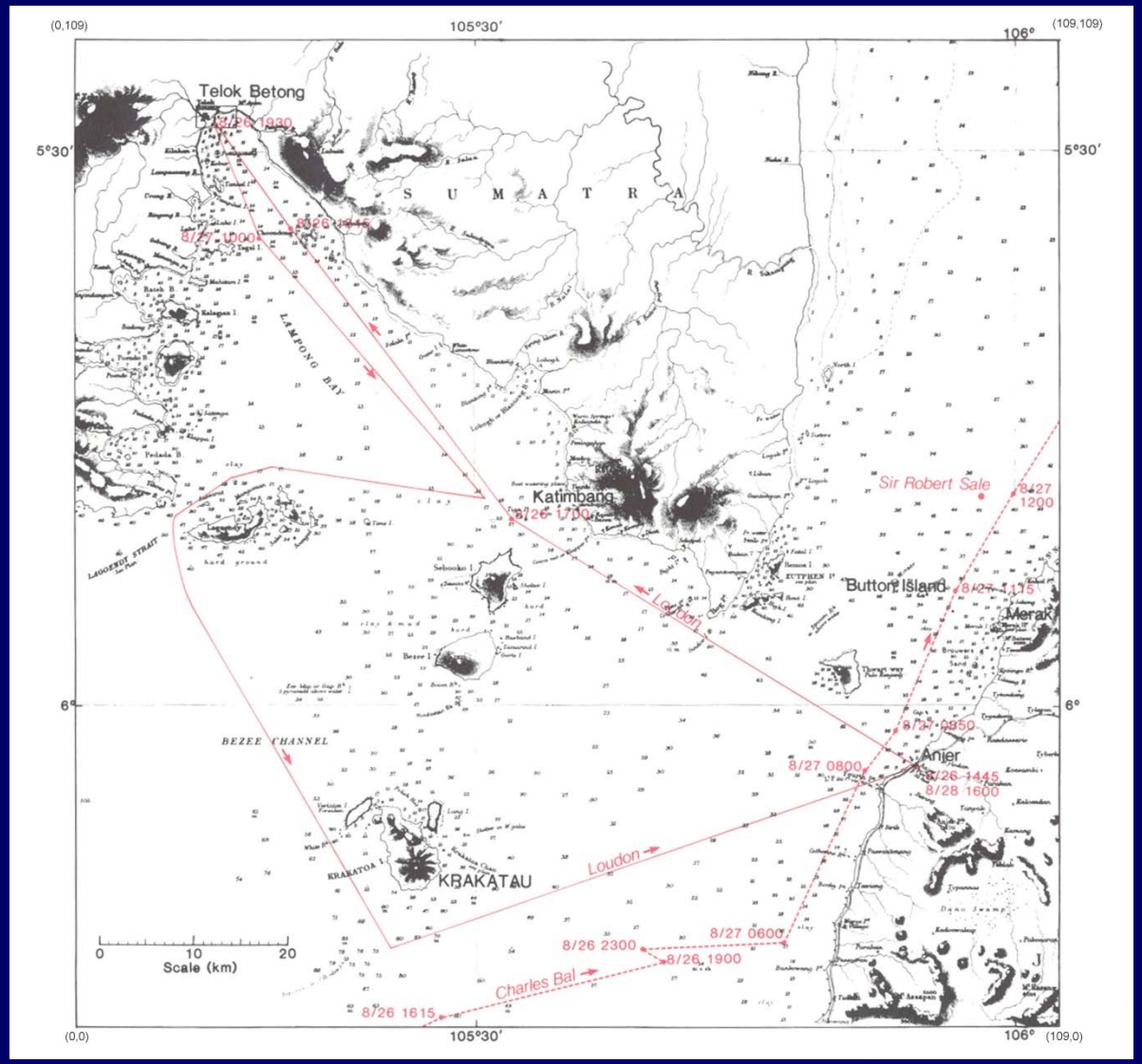
- **Blast waves cracked walls and broke windows up to 160 km away and atmospheric pressure shock waves from the explosions of Krakatoa circled the earth seven times and were recorded by barographs throughout the world**
- **The eruption was heard as far away as Rodriguez Island which is 4,653 km to the west-southwest**
- **The dust cloud from the eruption completely covered the area, total darkness continued for three days**
- **Ash from the eruption precipitated on the decks of vessels as far as 1,600 miles away and buried everything on nearby islands**
- **Ash from the eruptions was propelled to a height of 50 miles (80 kilometers) in the upper atmosphere blocking the sun and plunging the surrounding region into darkness for two and a half days.**
- **Dust and ash from the eruption encircled the Earth in 13 days forming a cloud that completely covered the upper atmosphere along a belt in the equatorial zone and later spread to higher latitudes causing unusually spectacular red sunsets for almost 3 years**
- **Of the estimated 21 km^3 erupted, it is estimated that ~4 km^3 of ash was injected into the stratosphere above 25 km. Global temperatures were lowered by as much as 1.2° C on the average and did not return to normal for 5 years, producing chaotic weather patterns**



A *Proto-Krakatau* Model

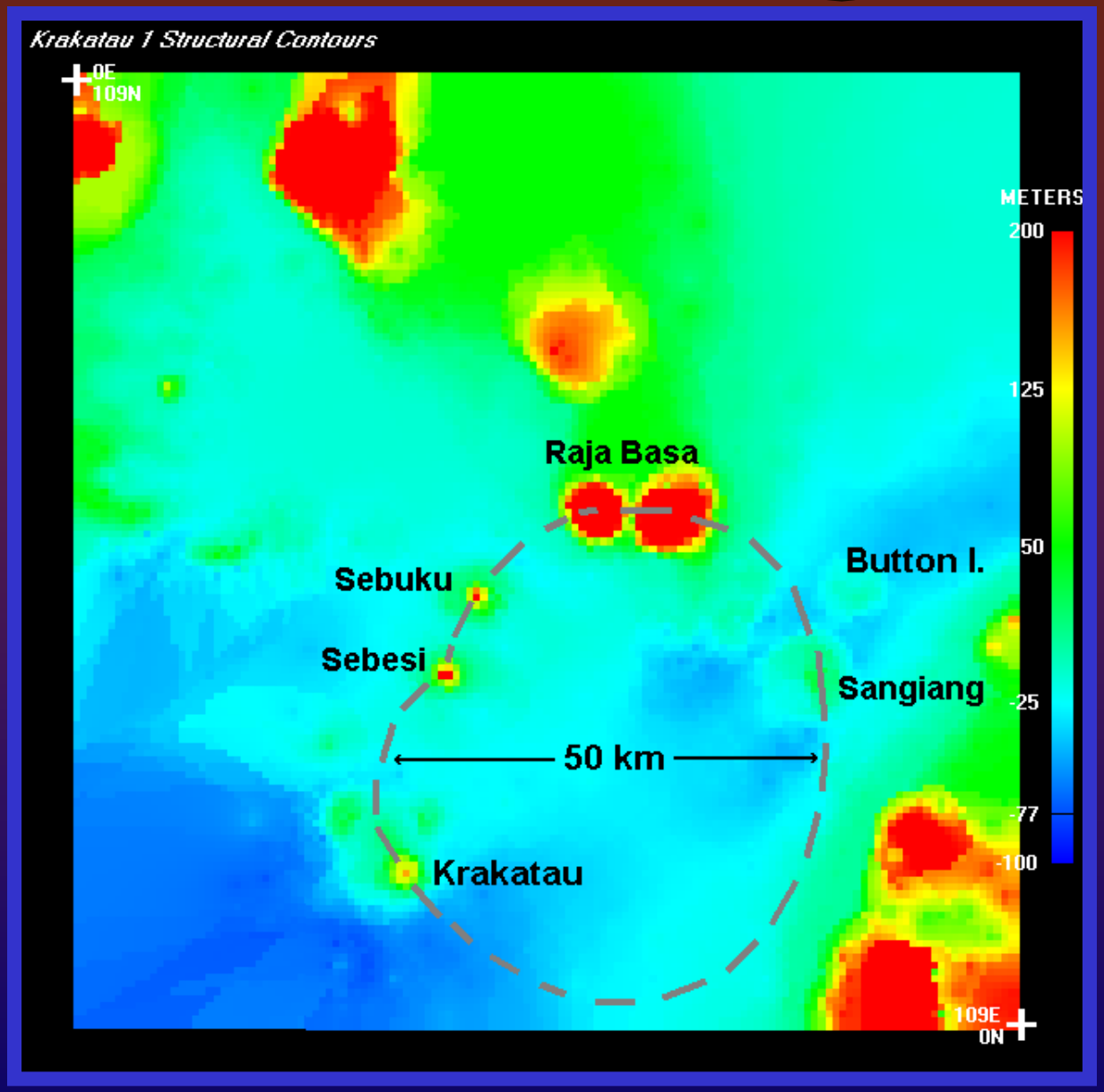
- Used code *Erupt3* to simulate the generalized progression of eruption phenomena and their impact upon topography
  - Generated initial regional topography by series of modeled eruptions along an island chain
  - Eruption progression involved initial phreatic eruptions, followed by ultraplinian and phreatoplinian phases, during which caldera collapse occurs, and ending with phreatic eruptions
  - Used boundary and initial conditions appropriate for a 50-km-wide caldera eruption with eruptive fluxes reaching 10^9 kg s^{-1} and erupted volume totaling ~200 km^3
- Employed detailed plume calculations made with *DASH* code
  - Plume height and structure, including height, temperature, particle concentration, and initial spread velocity
- Consulted with atmospheric modelers as to the implications of such a source on current GCMs
- Tested infrasound theory that eruption sounds might be heard in China nearly 4500 km distant

Bathymetry of the Sunda Straits



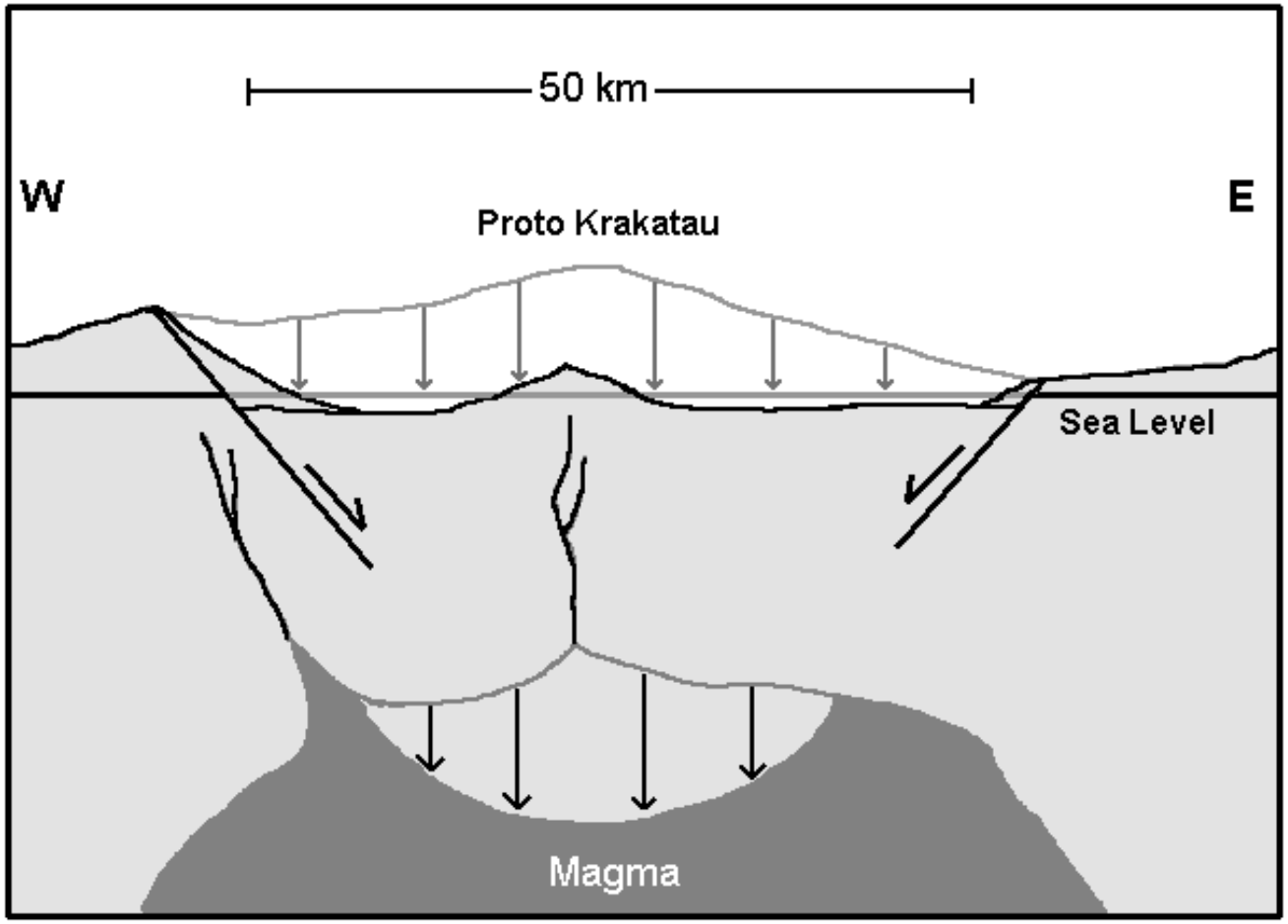
Pre-1883
(British Admiralty)

Post-1883
(Sigurdsson and Carey)

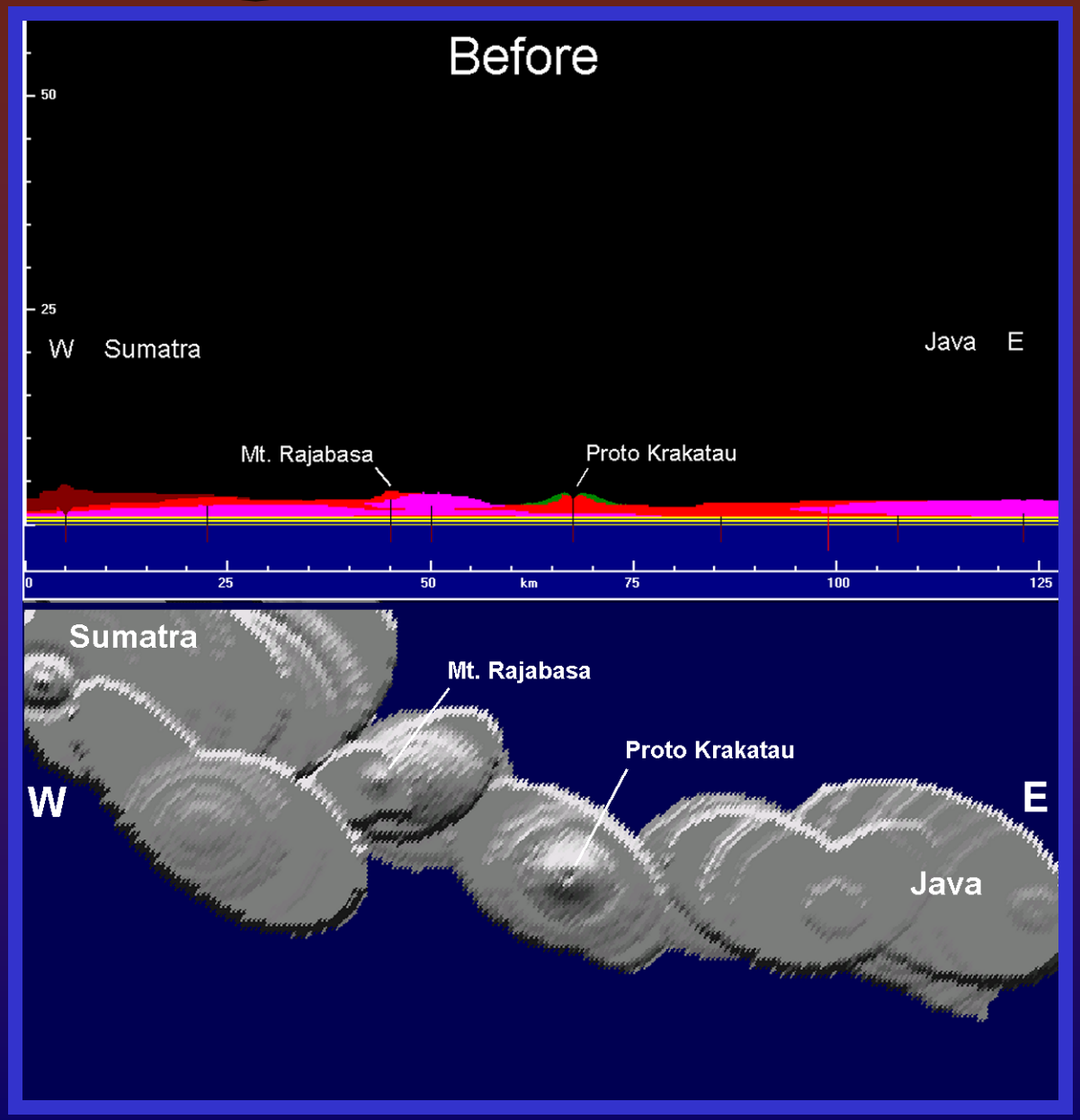


Pre-1883 bathymetry reveals a caldera

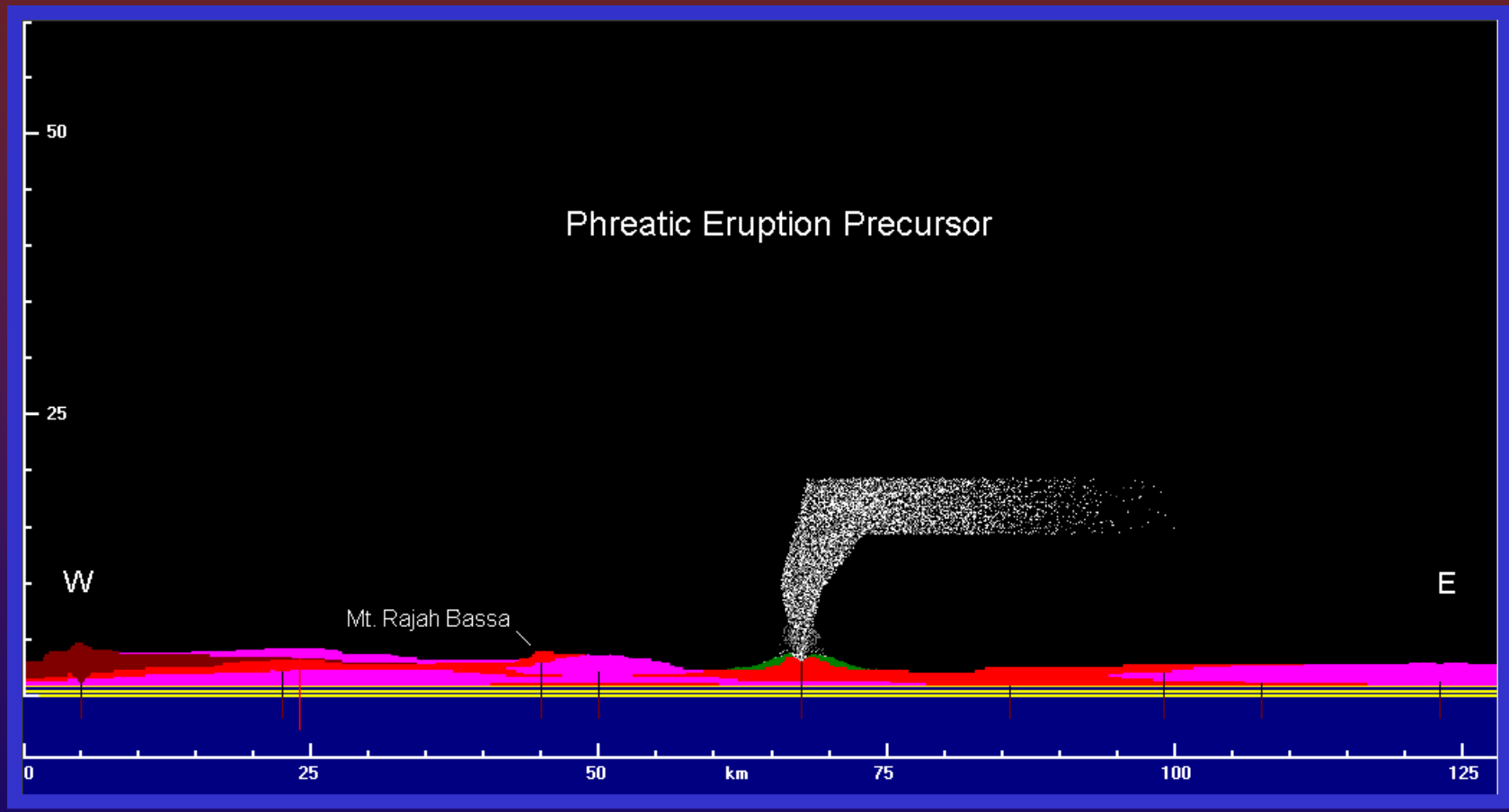
Hypothetical Cross Section



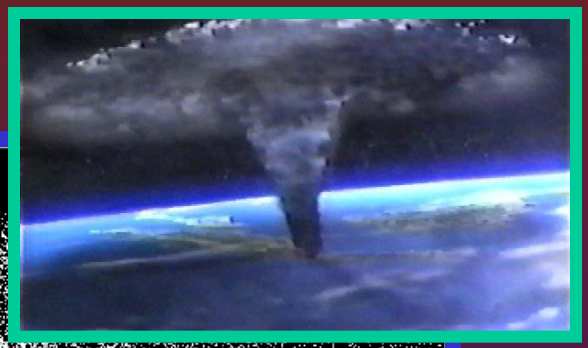
Modeled Initial Conditions

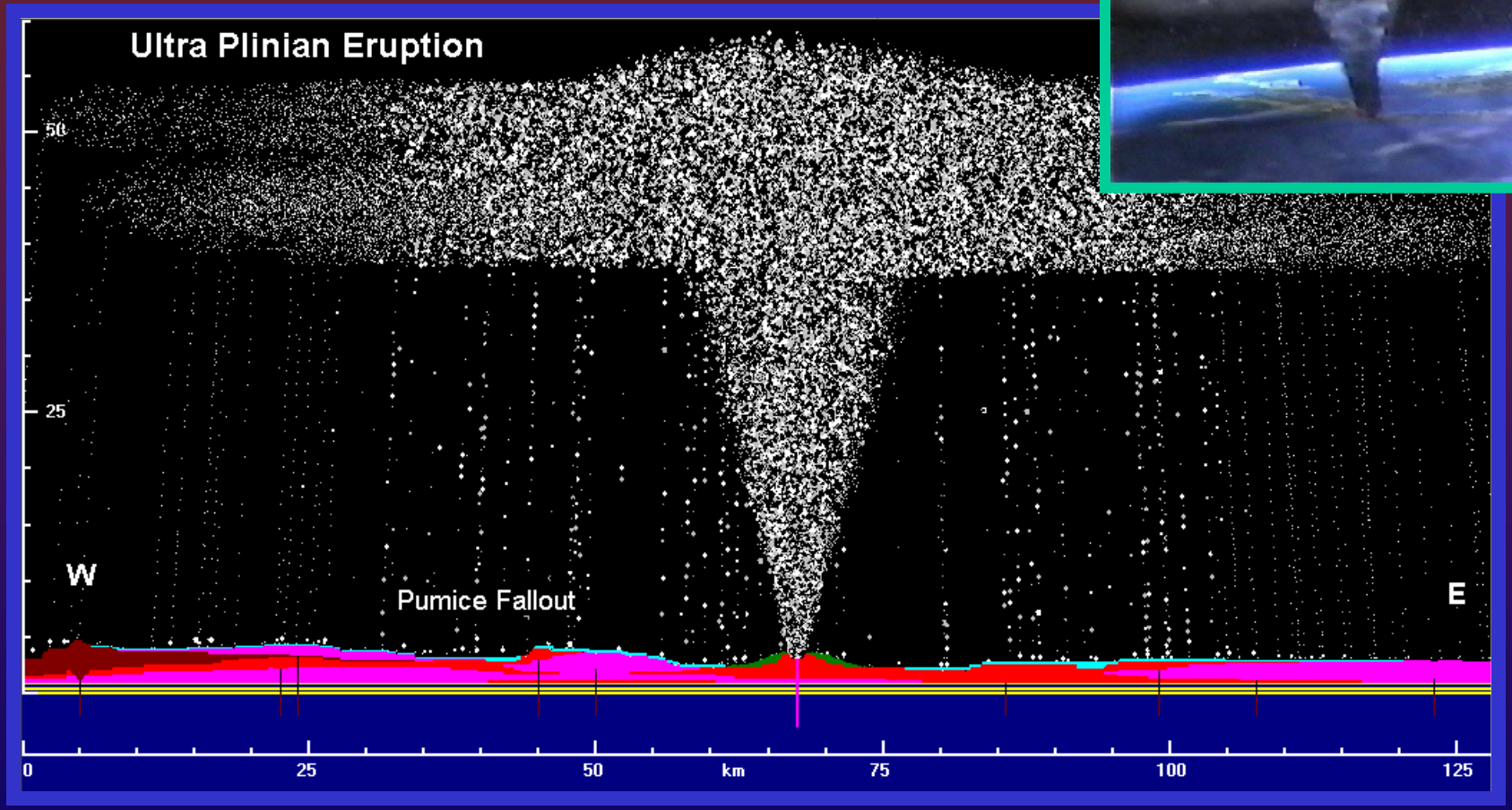


Modeled Precursor Phreatic Eruptions

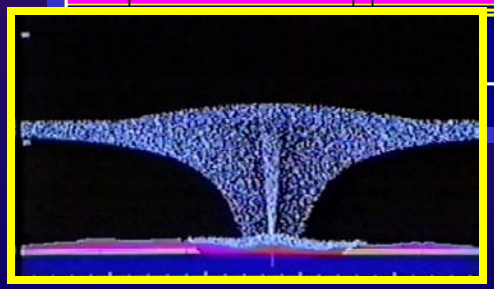


Modeled Initial Ultraplinian Eruption

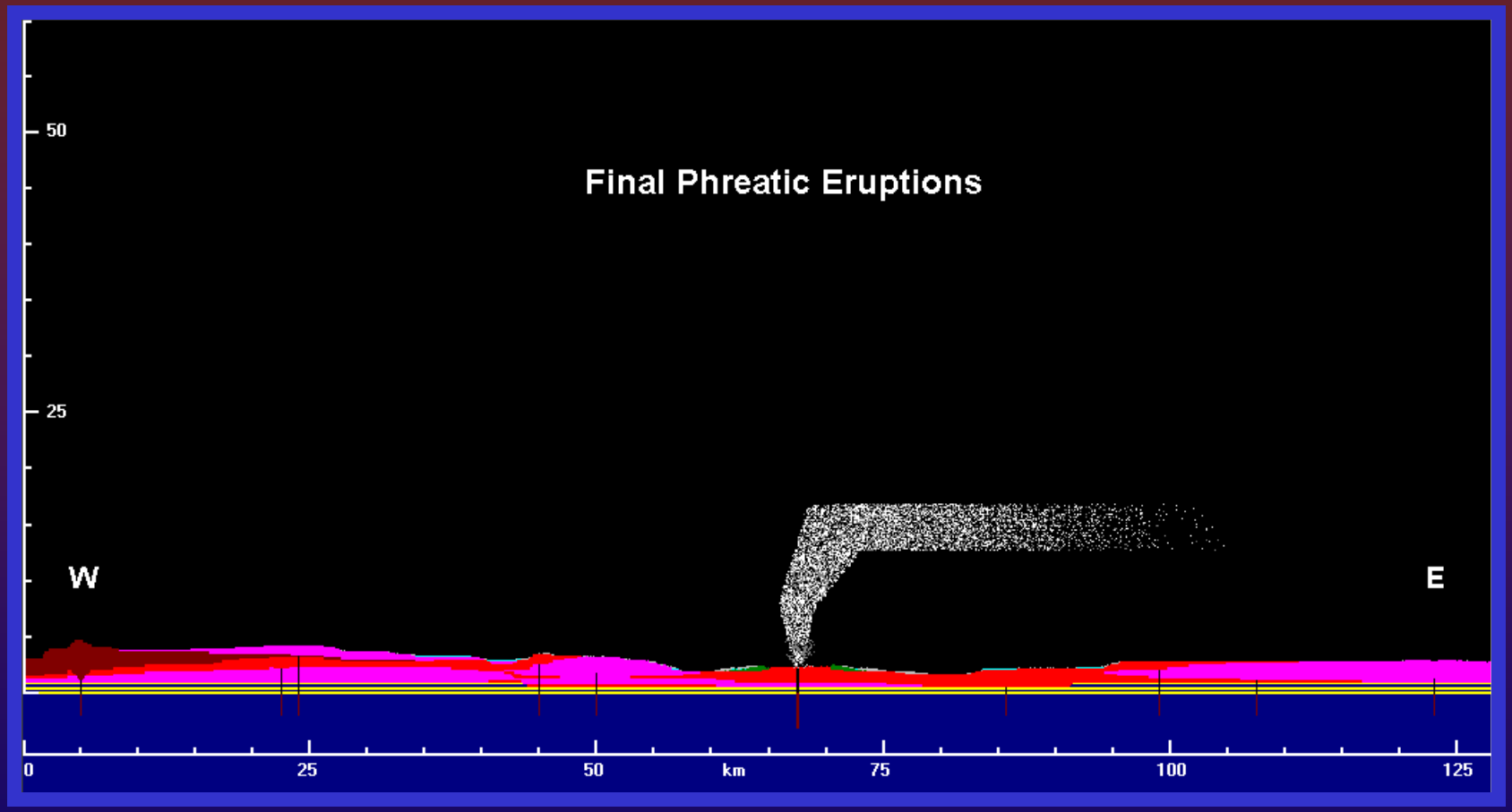




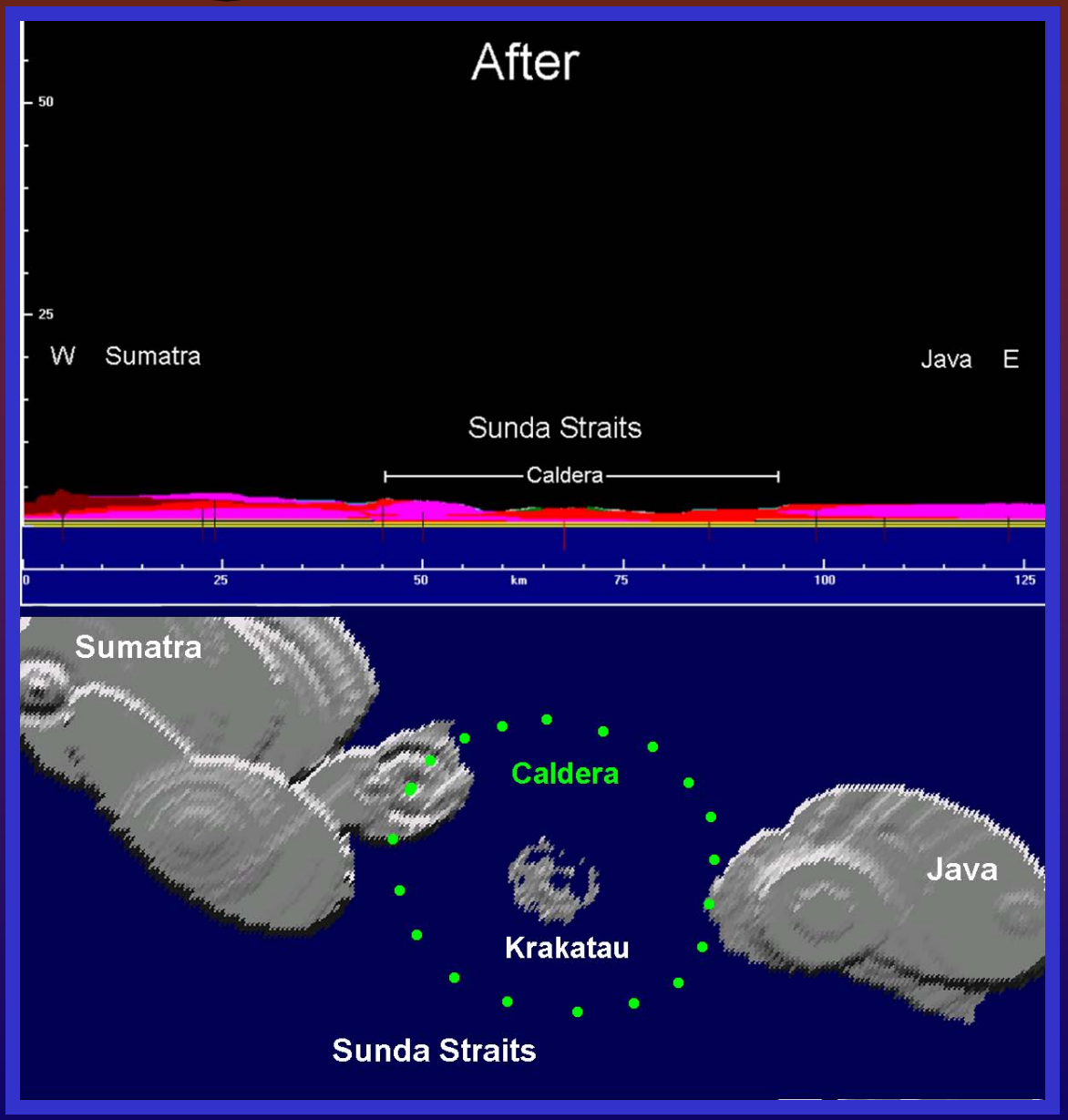
Modeled Phreatoplinian Caldera Eruption



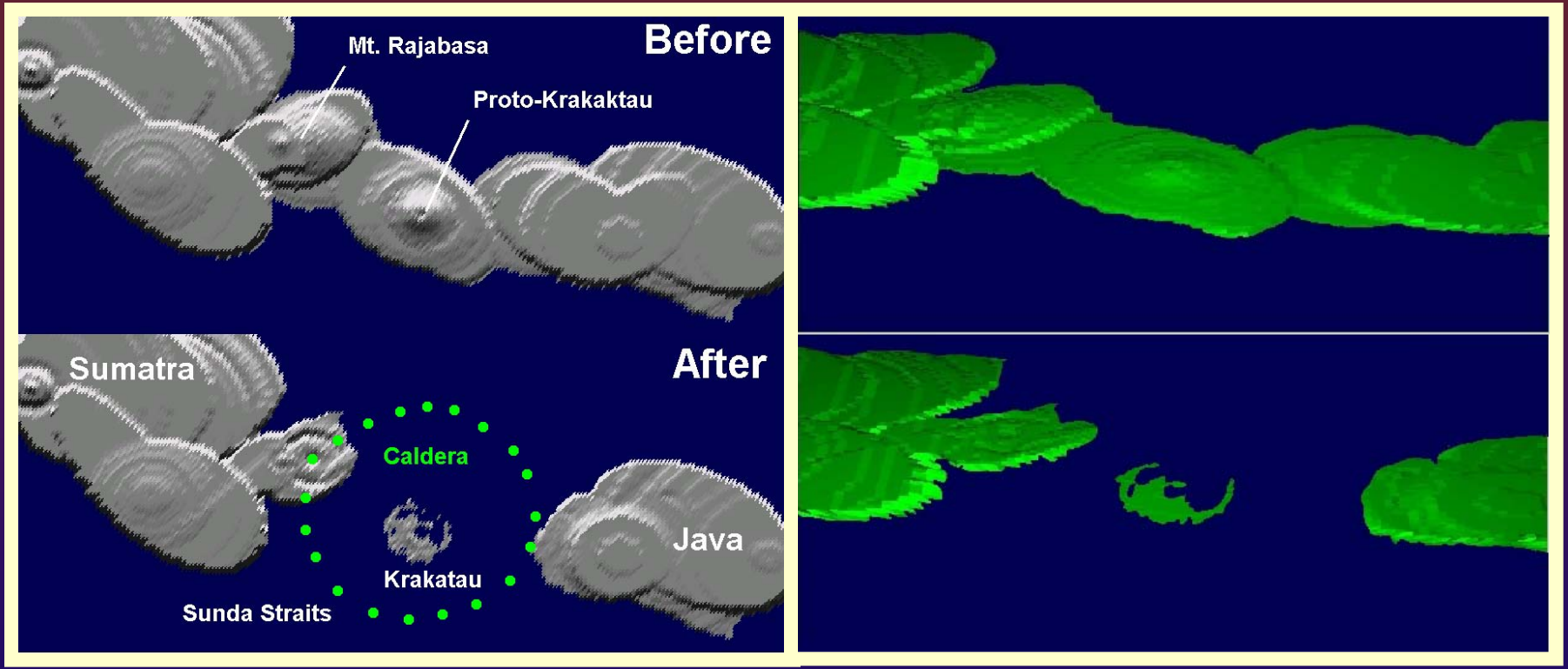
Modeled Final Phreatic Eruptions



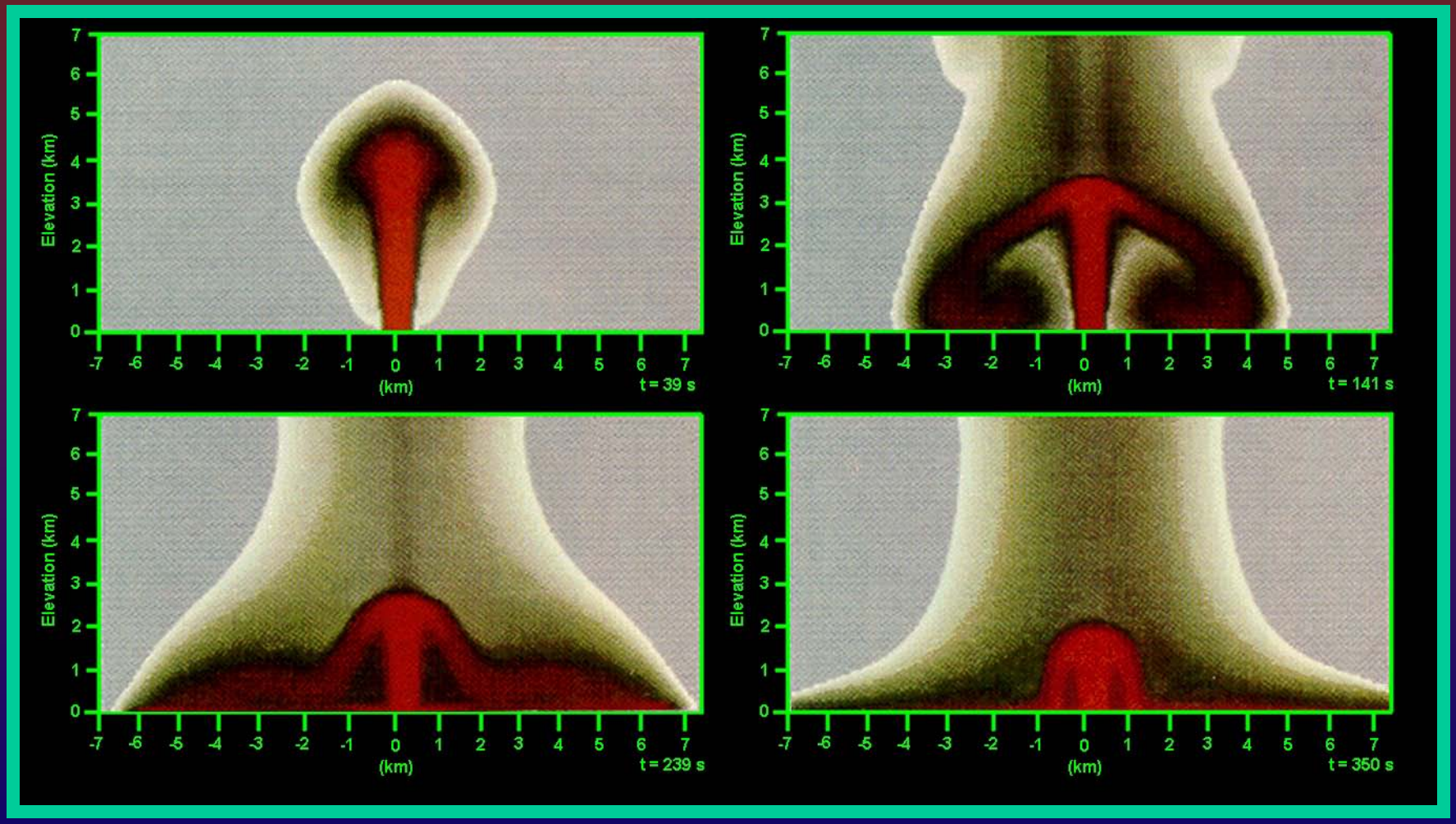
Modeled Final Conditions

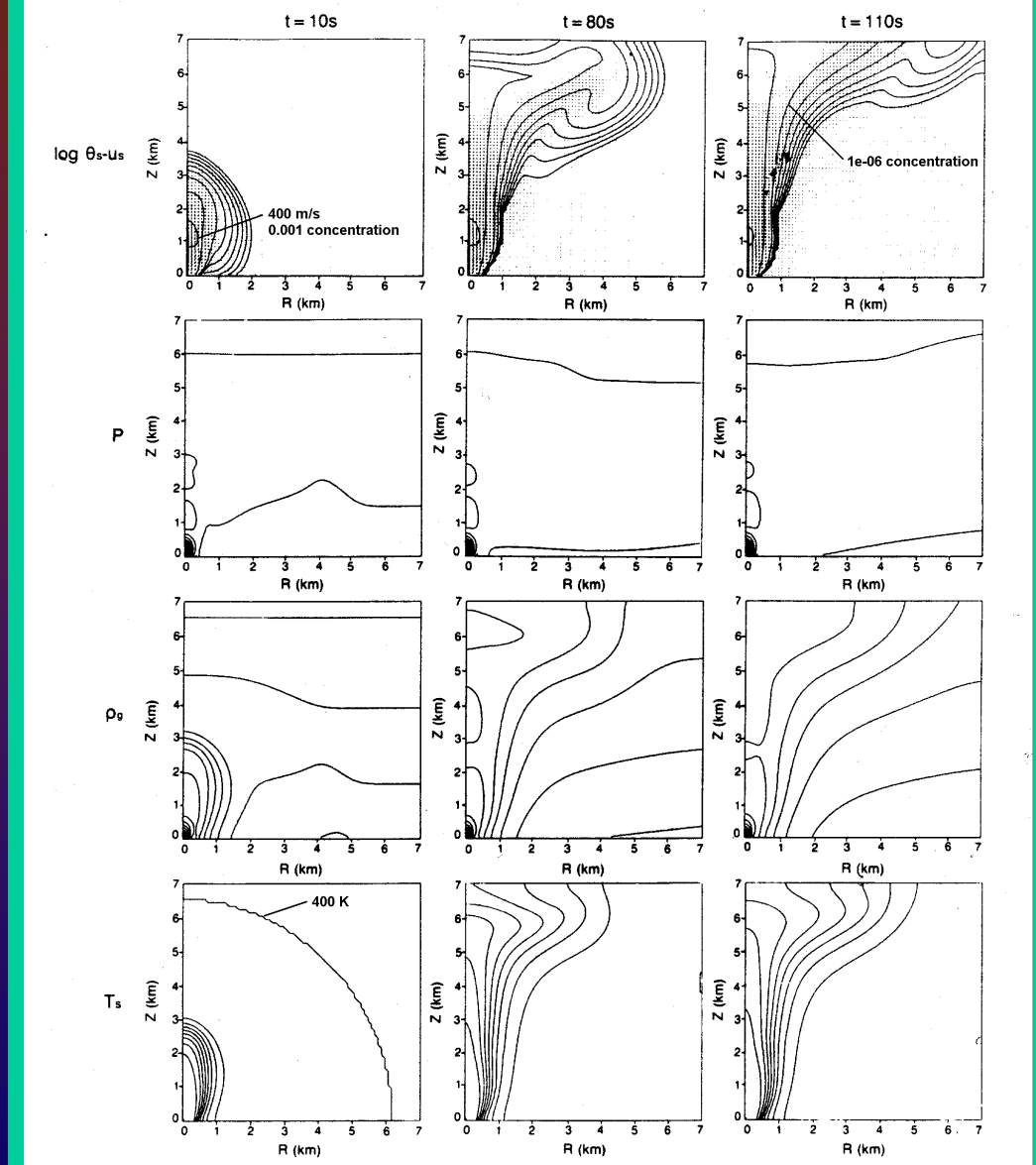


Topographic Changes



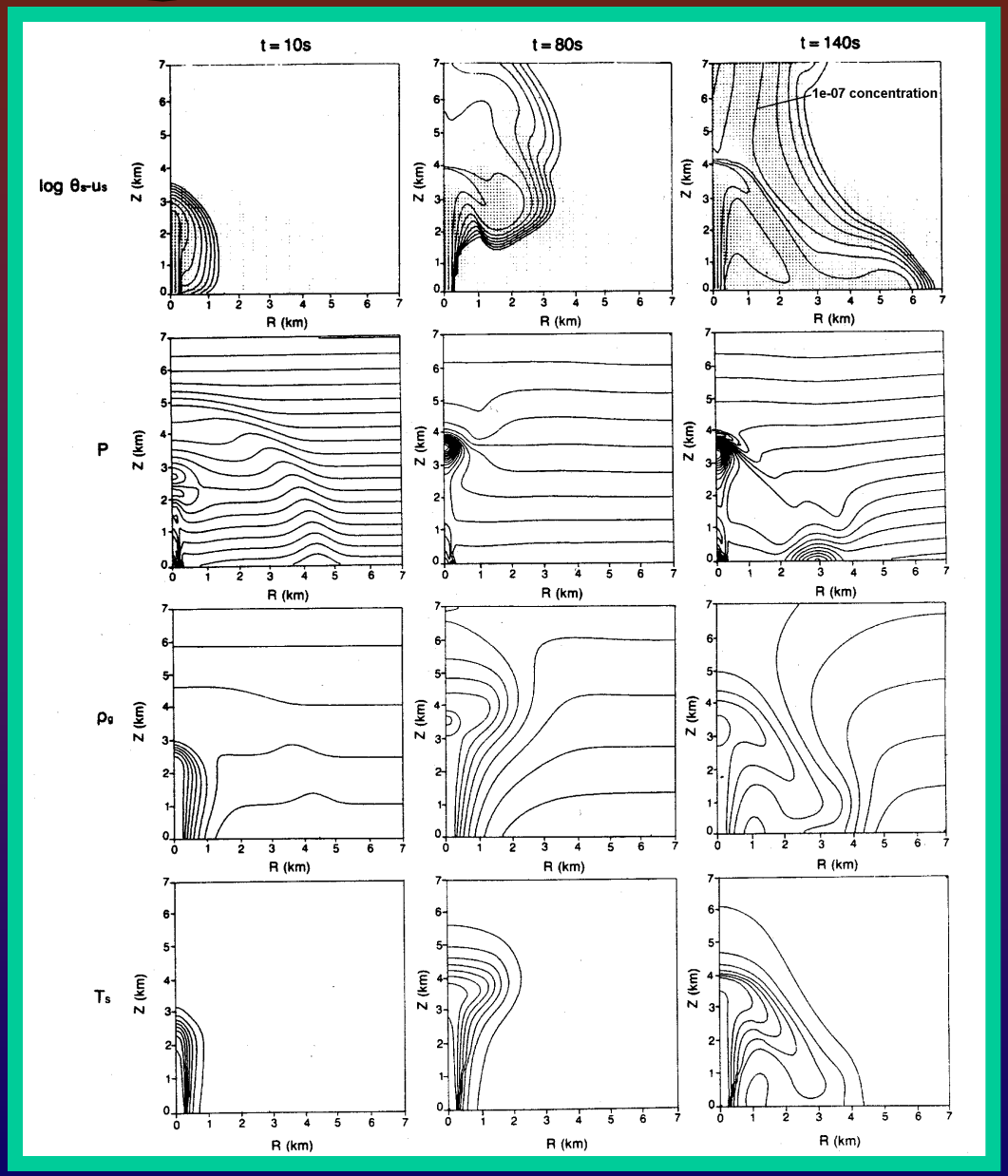
Simulation of Caldera Eruption Details





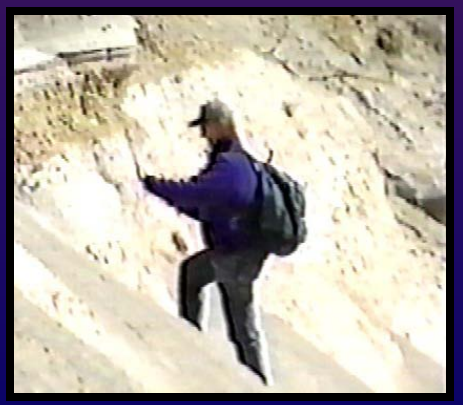
Simulated Plinian Plume Source Character

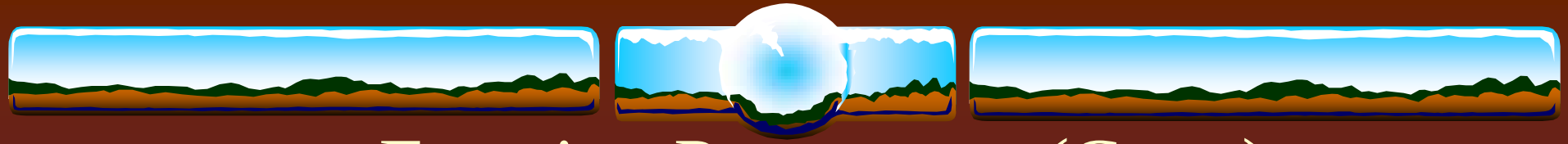
Simulated Phreatoplinian Plume Source Character



Eruption Parameters

- Magnitude
  - Collapse of 100 m over 50-km diameter caldera can involve eruption of ~200 km^3 of magma
  - Scaling of similar-sized eruptions predicts mass fluxes of ~10^9 kg s^{-1}
- Duration
  - Eruption of 200 km^3 of magma at 10^9 kg s^{-1} requires at least ~60 hours of continuous eruption
  - Continuous eruption not likely, so duration may have lasted from a week to over one month
- Tephra
  - Dominantly pumice and ash
  - For phreatoplinian eruption up to 50 wt-% of the tephra can be fragmented to fine ash (< 63 μm)
  - If 75 vol-% of the erupted products were phreatoplinian, 75 km^3 of fine ash were injected into the atmosphere





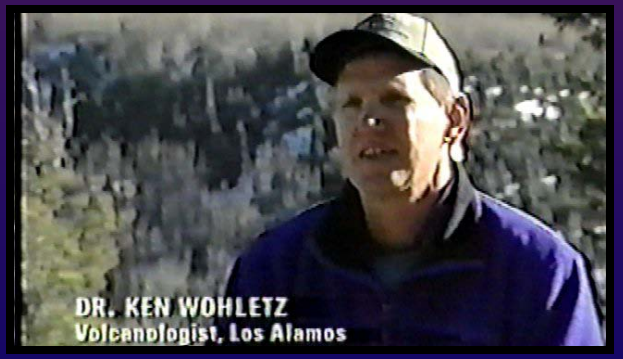
Eruption Parameters (Cont.)

- Gases
  - Dominantly H_2O
  - For strong water/magma interaction, a volume of water vaporized is nearly equal to the volume of magma in the interaction
  - If 75 vol-% of the erupted products experience strong water/magma interaction then 150 km^3 of seawater were vaporized, creating up to 200,000 km^3 of water vapor in the atmosphere
  - Likely a large portion (50 vol-% or more) condensed an precipitated from low altitudes
  - Remaining vapor likely formed ice crystals in the stratosphere
- Plume Structure
  - Erupted at speeds up to 650 m s^{-1}, the eruption column may have exceeded 50 km in height before reaching neutral buoyancy
  - From numerical models, tephra volume concentrations after mixing with the atmosphere are 10^{-6} or less
  - If the fine-ash component remained in the plume with water vapor that formed ice crystals, then the total plume volume may have reached several tens of million of km^3

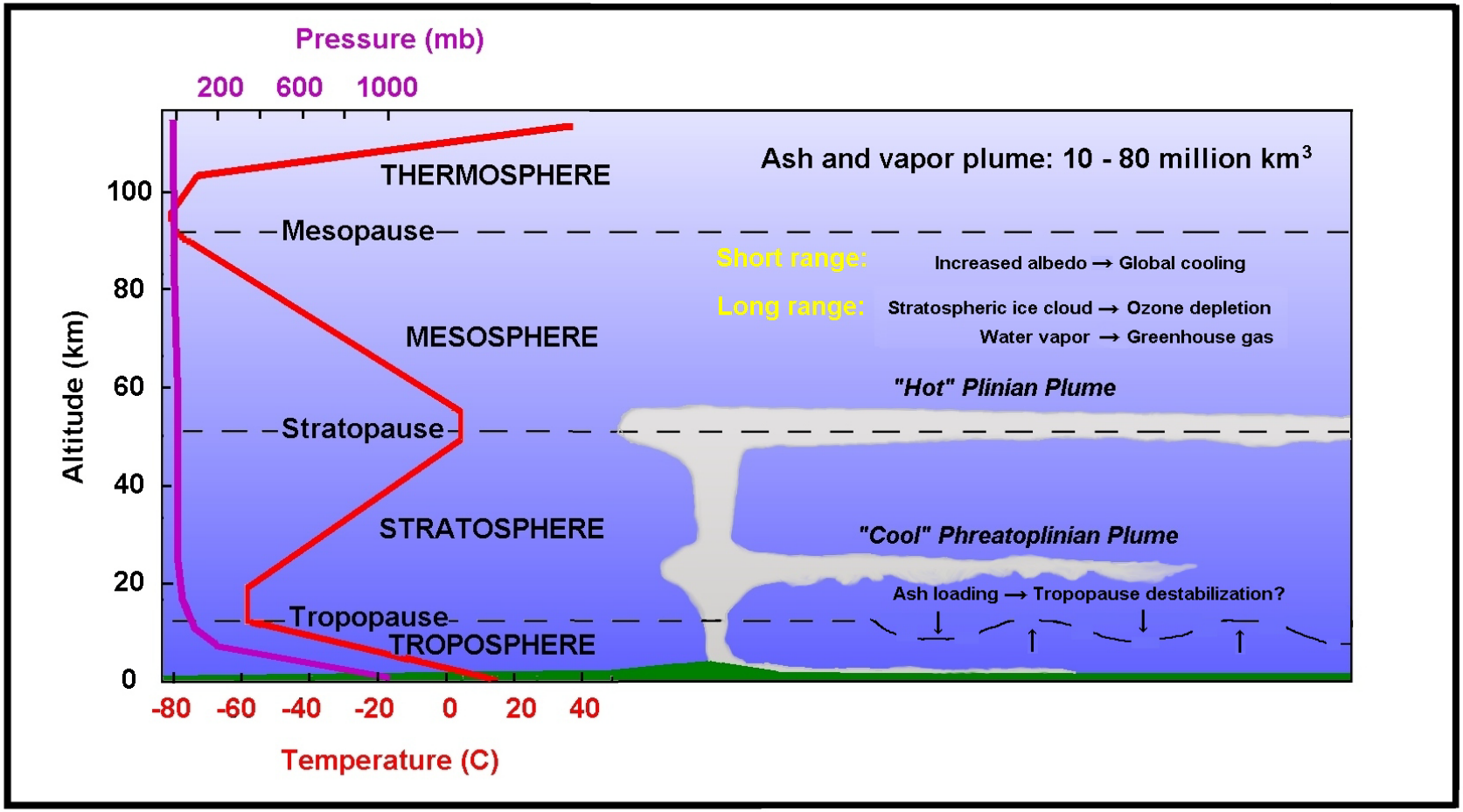
Atmospheric Wonderings

- Consider the large volume of the plume (10 – 80 million km^3)
- The earth's tropopause surface area is ~$5.2x10^8$ km^2
- Eruption plume could have produced a cloud layer from 20 to 150 m thick over the entire globe
- With the plume source near the equator, both north and south hemispheres would be affected
- Such a large magnitude volcanic plume has never been considered for GCMs, and its only analog might be the ejecta plume of the K-T impact.

- Application of nuclear winter models (soot) for the K-T impact indicate such a burden of particles in the stratosphere would cause collapse of the troposphere
- In addition, the large volume of water vapor may produce huge stratospheric ice clouds, leading to destruction of the ozone.

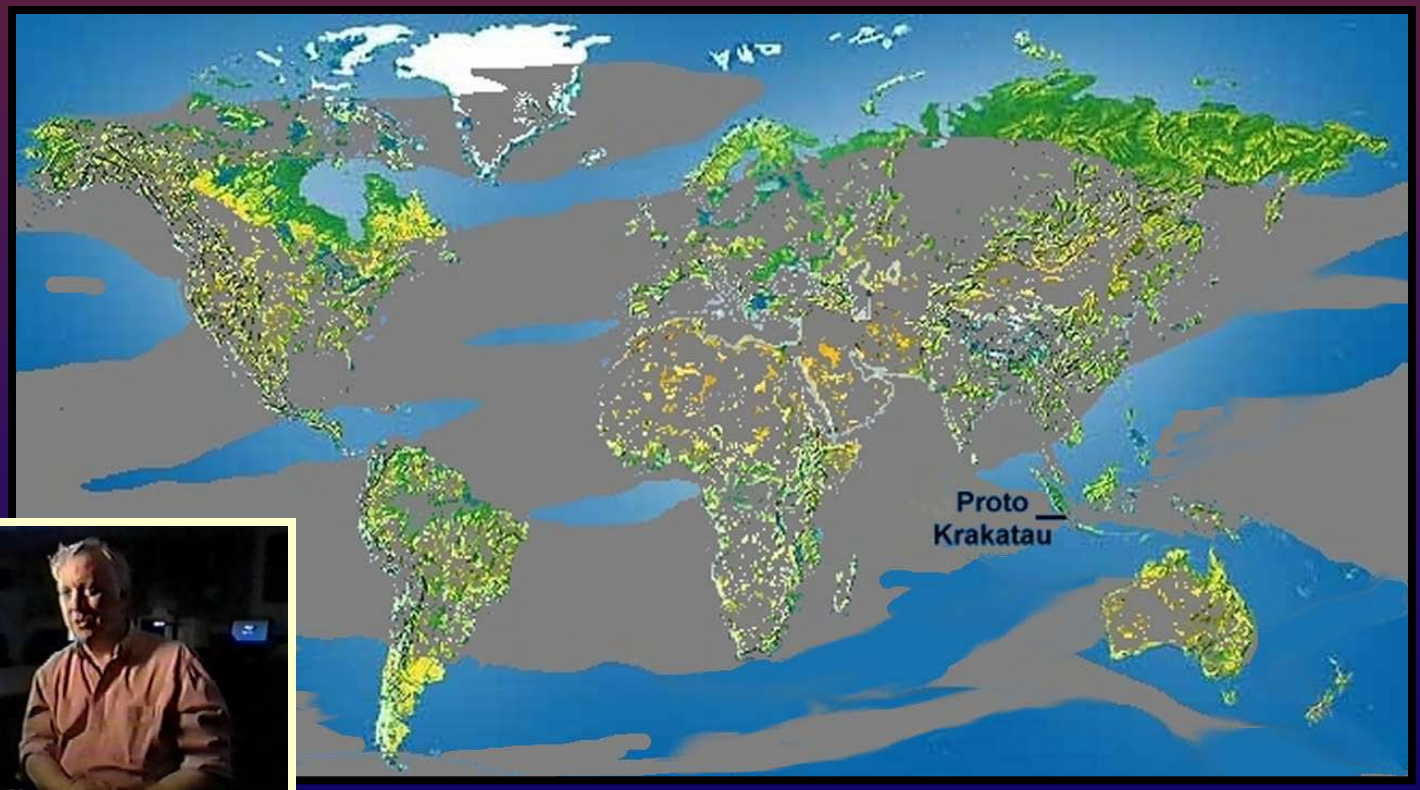


Atmospheric Wonderings (Cont.)



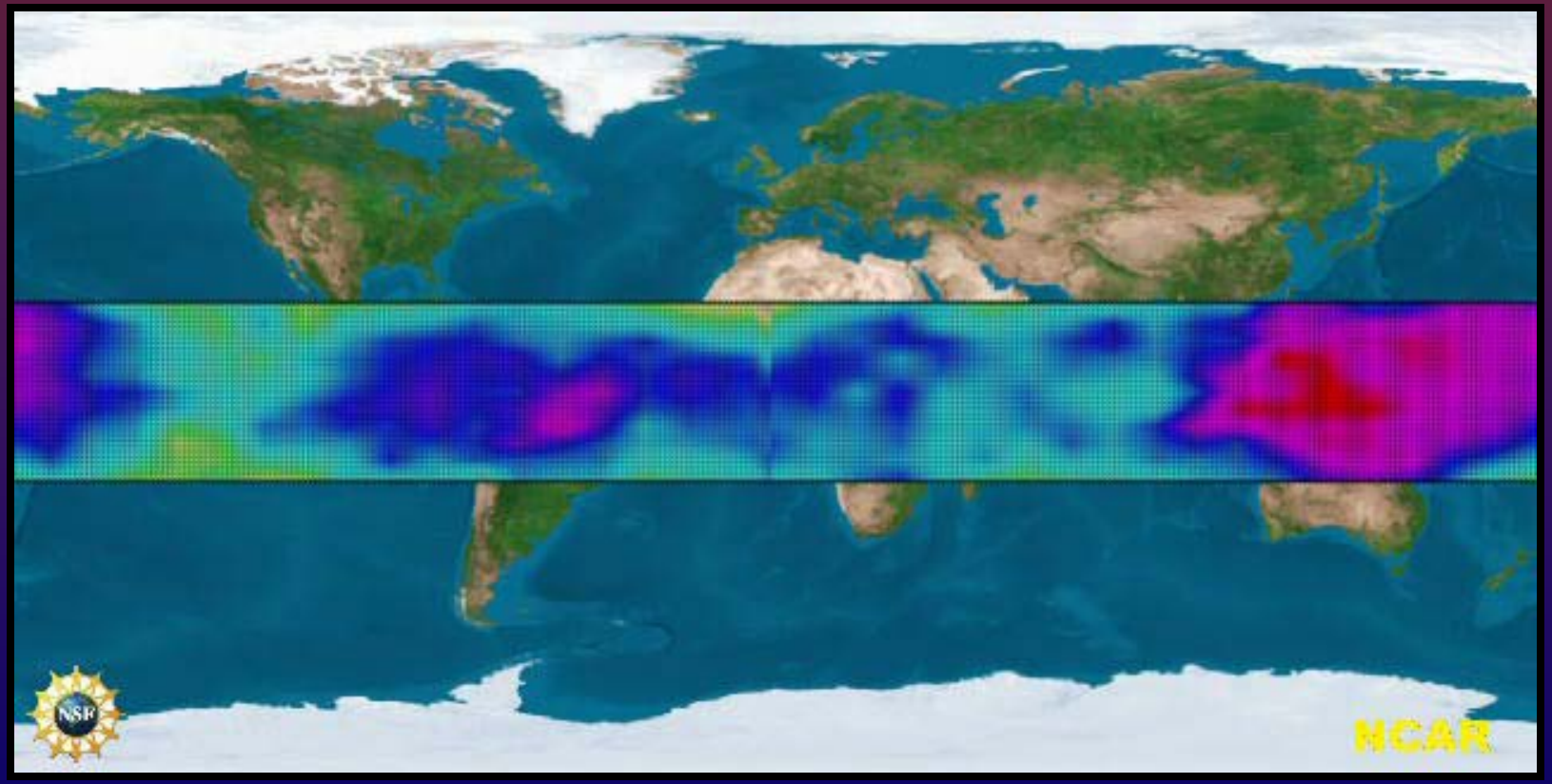
Atmospheric Wonderings (Cont.)

- The global climate impact might involve:
  - Initial global cooling by 5 to 10° C or more lasting over 10 to 20 years, caused by the increased global albedo
  - Subsequent global warming with remaining water vapor acting as a greenhouse gas and decreased ozone



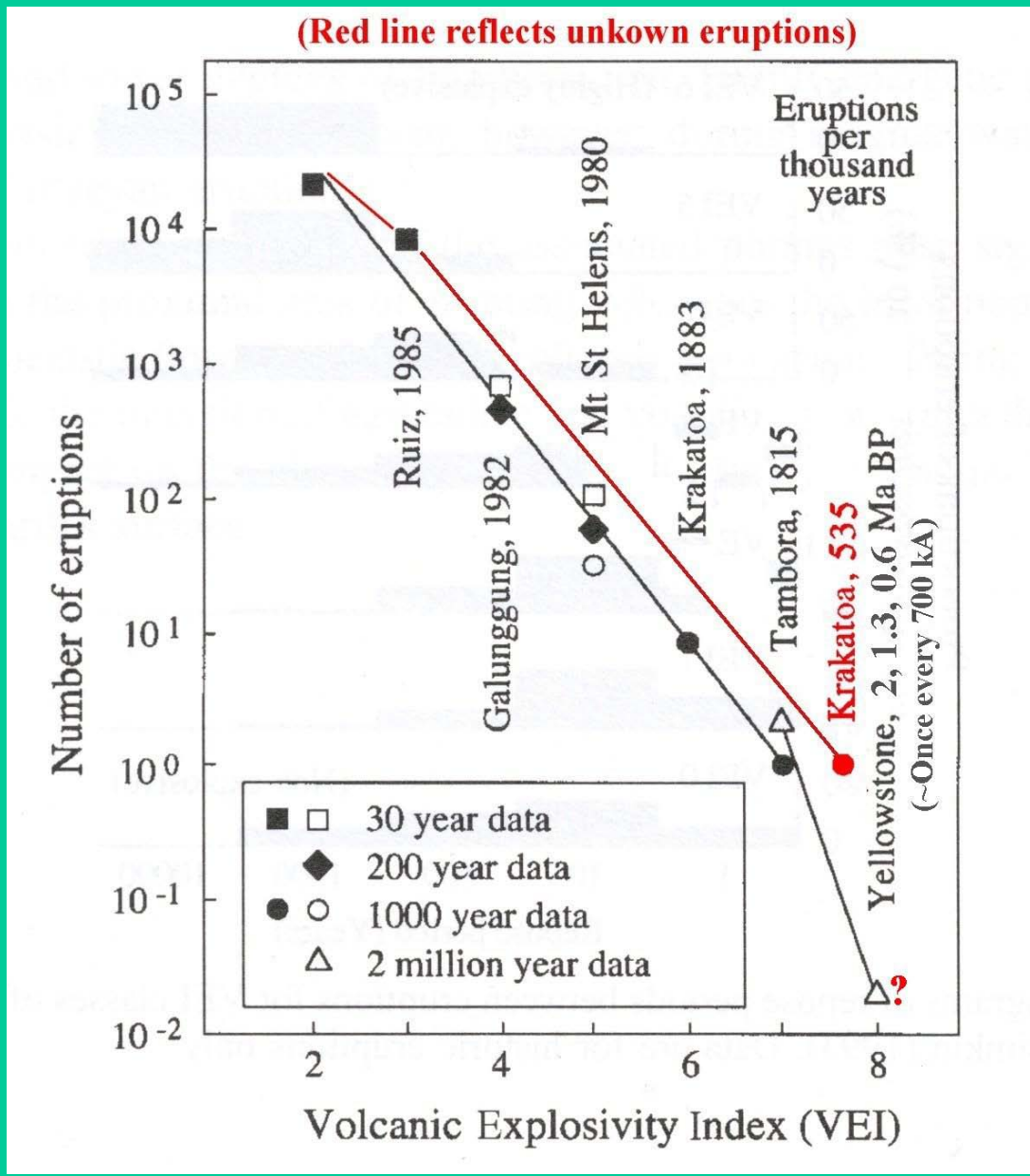
Stratospheric Circulation at the Equator

(massless particles released at 17 km, colors denote temperatures)



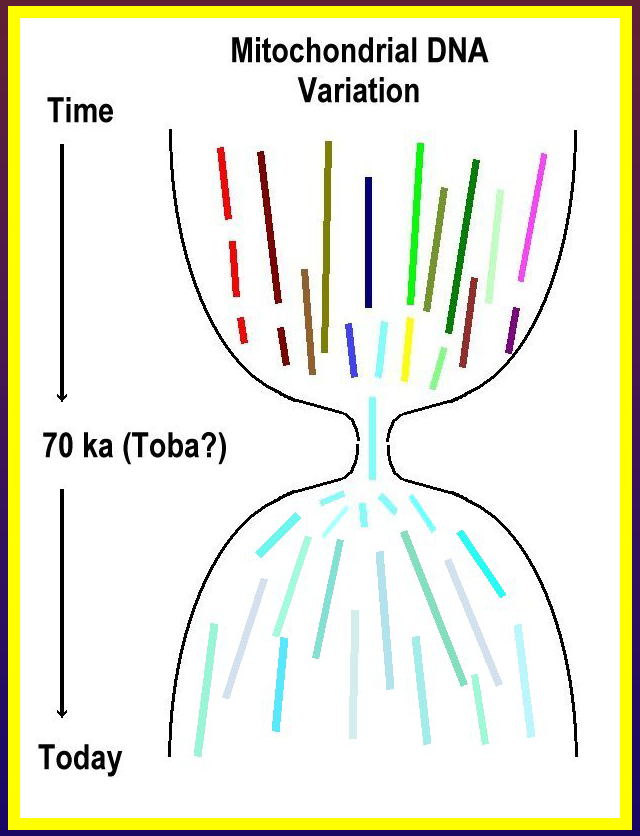
VEI Frequency Plot Revision

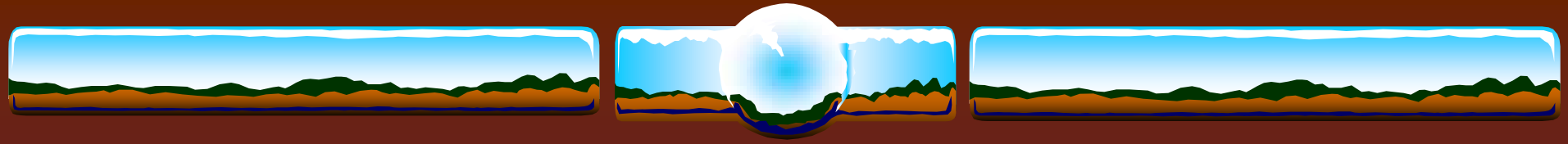
- Frequency of magnitude 8 not considered historical
- 535 Krakatoa (?) suggests larger frequency of magnitude 7-8 eruptions
- Large, historic caldera-type eruptions may not be recognized because of their location in shallow seas or concealed by vegetation



Is Adaptation to Volcanic Crisis Programmed in our DNA?

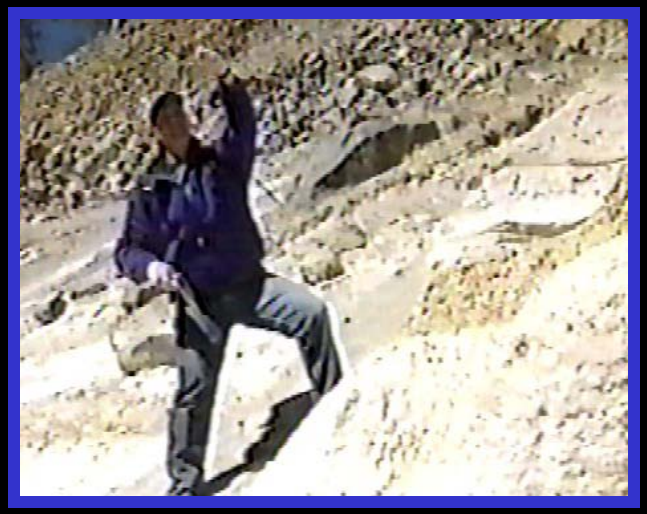
- In 1998 Stanley Ambrose proposed a volcanic winter hypothesis for recent human DNA differentiation
- Mitochondrial DNA passed on by mother; the rate of its mutation is fairly constant over time
- Small variation found in today's population and the number of mutations suggest common ancestors dating back ~70-80 ka (Toba's eruption)
- A "bottleneck" of this DNA suggests reduction of world population to a few thousands (Rogers and Jorde)
- Do existing lines carry a "survival" signature?





Conclusions

- The historical and archaeological evidence is abundant and so far has stood up to academic review. In fact this evidence is now a major topic for Dark Ages societies
- The Proto-Krakatau hypothesis is supported by somewhat more circumstantial evidence
- The global atmospheric impact is very hypothetical, requiring new GCM model to approach a perturbation of this magnitude
- The global consequences to humanity of a *super eruption* (*Catastrophe)* are much more complex and far reaching than has ever been considered. Such an event can fundamentally and permanently change human history
- There are numerous potentially active calderas that can erupt in the near future with the magnitude of Proto-Krakatau



The End